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AIR TRAFFIC AT AN UNCONTROLLED AIRPORT AND EXPECTED ALERT RATES FOR COLLISION DETECTION LOGICS

DEPARTMENT OF TRANSPORTATION · UNITED STATES OF AMERICA

JUNE 1976

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16. Abstract

To provide preliminary design data for refinement of the Automated Terminal Services (ATS) concept, a study of airport traffic was initiated. Data was acquired on aircraft behavior in a typical traffic pattern at Manassas Airport: an uncontrolled, primarily general aviation airport. A time step computer model of the multi-aircraft traffic situation was generated. Various statistics of the traffic were extracted and potential collision warning logics exercised to determine alarm rates. The results have implications for both the effectiveness of airborne collision avoidance systems in the traffic pattern and of ground based concepts that include threat detection such as ATS.

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CONCLUSIONS

To provide preliminary design data for refinement of the Automated Terminal Services (ATS) concept [1], a study of airport traffic was initiated. Data was acquired on aircraft behavior in a typical traffic pattern at Manassas Airport: an uncontrolled, primarily general aviation airport. A time step computer model of the multi-aircraft traffic situation was generated. Various statistics of the traffic were extracted and potential collision warning logics exercised to determine alarm rates. The results have implications for both the effectiveness of proposed airborne collision avoidance systems in the traffic pattern and of ground based concepts that include threat detection such as ATS.

Data was acquired on the multi-aircraft traffic situation for two 45 minute periods at a single airport. This small sample yielded statistics compatible with more extensive NASA studies of the traffic pattern [6,7]. However, these NASA studies did not include simultaneous aircraft track data. The alarm rate computations require relative aircraft positions and therefore are based exclusively on the data presented here.

Specific results of this study include:

1. Some observations (based on the 45 minutes of 150 operations per hour data) have impact on the general design of an automated advisory service such as ATS. They are:

   a. Touch-and-go operations account for over 50% of the total operations.

   b. Only about 11% of the tracks exhibit unexplained non-standard pattern behavior, but another 16% execute maneuvers that can be interpreted as escape behavior due to traffic.

   c. At the point of passing abeam the runway threshold on downwind leg, a given aircraft always had at least one and as many as five other aircraft ahead in the landing sequence with an average value of 2.6. The sequence order was preserved to landing for all aircraft that actually landed during the 45 minute sample period except for one instance of cutting into the pattern and two straight-in approaches.

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2. Alarm rates were briefly studied for two classes of threat detection logics: those using only range and range rate data, such as might be available in an <u>airborne</u> collision avoidance system, and those also using vector miss distance information, such as a <u>ground based</u> ATS system would have available through tracking. Parameters for warning time, miss distance, and range threshold were varied to determine sensitivity of the alarm rates to these values. Some significant results are:

a. At warning times of ~25 seconds, the use of miss distance information can reduce alarms by 61% with respect to a τ-with-immediate-range only criterion.

b. At the high 150 operations/hour rate, there is a 50% chance that an aircraft will be declared in conflict during a single operation ("track") using the "airborne" logics. This reduces to 25% with the "ground based" systems.

c. If an alarm is given from an airborne system, there is a 50% probability that an additional aircraft besides the threat aircraft is within 0.5 nmi. This raises questions about pilot identification of the correct threat when the alarm is given without bearing information.

d. Approximately a third of the alarms given by a ground based system are "true" alarms in the sense that actual "escape" behavior was observed for those aircraft during the data collection effort.

e. Using different alarm logics (and/or parameters) in different regions of the traffic pattern can result in a reduction of alarms (e.g., 33% reduction demonstrated) and an increase in the fraction of alarms that are "predictive" of true events. This type of adaptation can be easily arranged in the software of a ground based system and is expected to be useful in ATS design.

3. As operation rates increased, it was observed that regularity of the traffic and conformance to standard procedure increased. It is expected that this same effect would occur if an electronic system were monitoring and encouraging well structured traffic.

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1. INTRODUCTION

A concept for providing Automated Terminal Services (ATS) is being explored within the FAA Office of System Engineering Management. This ATS concept proposes a scanning beacon radar and minicomputer at each ATS airport, with computer generated voice messages transmitted on VHF aeronautical radio to the pilots. Such a system would be used at airports that might otherwise require the installation of a manned control tower. It also could play a role in reducing the number of hours a tower would be manned at presently controlled airports. Along with other services, a key safety feature of this system would be automatic detection of conflicts between aircraft and warning to the pilots of the potential collision threat. The concept is described in detail in the report FAA-EM-76-6, "A Description of the Automated Terminal Services Concept" [1].

To provide preliminary design data for ATS, a study was initiated to 1) observe air traffic in close proximity of the VFR traffic pattern, 2) create a realistic model of such traffic providing a time stepped picture of the traffic over the period observed, and 3) perform an analysis of traffic behavior and the alarm rate properties of possible threat detection logics in the pattern.

This report contains data on air traffic observed at the Manassas Municipal Airport (Davis Field), an uncontrolled general aviation airport located in Virginia which is typical of the class of airports considered for ATS. Alarm rate results of applying several possible logics for the automatic collision detection function are presented. Insight into the behavior of threat detection in the traffic pattern is provided by comparing potential ATS alarm rates with those that might be experienced by an airborne collision avoidance system (ACAS).

While this study is essentially a single point measurement of the traffic pattern at one airport, the statistics acquired are consistent with the fairly extensive multi-airport results on traffic behavior in the VFR traffic pattern acquired by other investigators [6 and 7]. However, these earlier studies considered each aircraft track entirely independent of other tracks and then collected total statistical descriptions of the traffic. In this process, relative information about aircraft trajectories is not obtained, and the performance of threat detection logics can not be evaluated using this data. The alarm rates given here are therefore based only on the Manassas data described in this report.

Organization of the document is as follows: The method of traffic observation and the creation of the model is described in Section 2. Section 3 contains summary description of the traffic, including traffic pattern characteristics such as pattern dimensions and interarrival times. The model is then systematically studied for alarm rates under several different logics and parameter sets for detection of collision hazard. This is described in Section 4. Section 4 also contains a study of true and false alarms in various parts of the pattern (under a suitable definition of "true" alarm). The analysis in Section 4 is directly relevant to analyzing the relative behavior of airborne collision avoidance systems and ground-based systems in the traffic pattern environment. Summary is presented in Section 5.

2. THE TRAFFIC MODEL

This section describes the process of obtaining the primary data sets, the two traffic models of Manassas Airport. It also contains an estimate of accuracy of these models. Various terms and abbreviations are defined in Appendix C.

2.1 Choice of Airport

Manassas Municipal Airport (David Field) in Virginia was chosen as the uncontrolled airport to be studied. This choice was made after comparison of uncontrolled airports in the vincinity of the Washington National and Dulles Airports. The factors considered were that: 1) the airport should be busy enough, (Manassas experienced 80,000 annual operations in 1974) and 2) should be typical in its operating practices (Manassas is a single runway airport, follows a standard left hand pattern, allows touch and go, and has no unusual topography).

Table 2-1 summarizes Manassas airport data. Figure 2-1 shows the map of the airport and vicinity

2.2 Overview of the Models

The output data sets consist of two models of traffic in the immediate vicinity of Manassas airport corresponding to two traffic densities, low and high. These two models are referred to as Manassas I and Manassas II respectively, throughout this report. Each model represents 45 minutes of real traffic. It consists of a data set, ordered in time on a 4 second scan by scan basis, giving data on all aircraft at each time epoch. Thus, at each scan, $X, Y, Z, \dot{X}, \dot{Y}, \dot{Z}$ information is provided for each aircraft in the system. The data, in this static form, exists on tapes. The data formats are described in Appendix D, with tapes presently stored at MITRE/Washington.

2.3 The Method

Appendix A describes full experimental details of how raw data was collected and how it was reduced into final data sets. A brief description is provided in this section.

The raw data was obtained by manual observation at the airport. The information gathered was absolute times of important events in aircraft profiles and speed and position on downwind leg. The process involved 6 observers. Each observer was equipped with a portable cassette tape recorder for recording his commentary in real time and a pair of binoculars for observing

TABLE 2-1

MANASSAS MUNICIPAL AIRPORT (HARRY P. DAVIS FIELD)

Location: 38° 43' N - 77° 31' W

Altitude: 186 feet MSL

Single Runway (dominant use: RWY 34)

Runway Length: 3700 feet

UNICOM at 122.8 MHz

Touch and Go's allowed

Annual Operations Count: (1974 Data Airport Manager's Estimates)

GA local	40,000
GA Itinerant	39,000
Air Taxi	1,000
Total	80,000

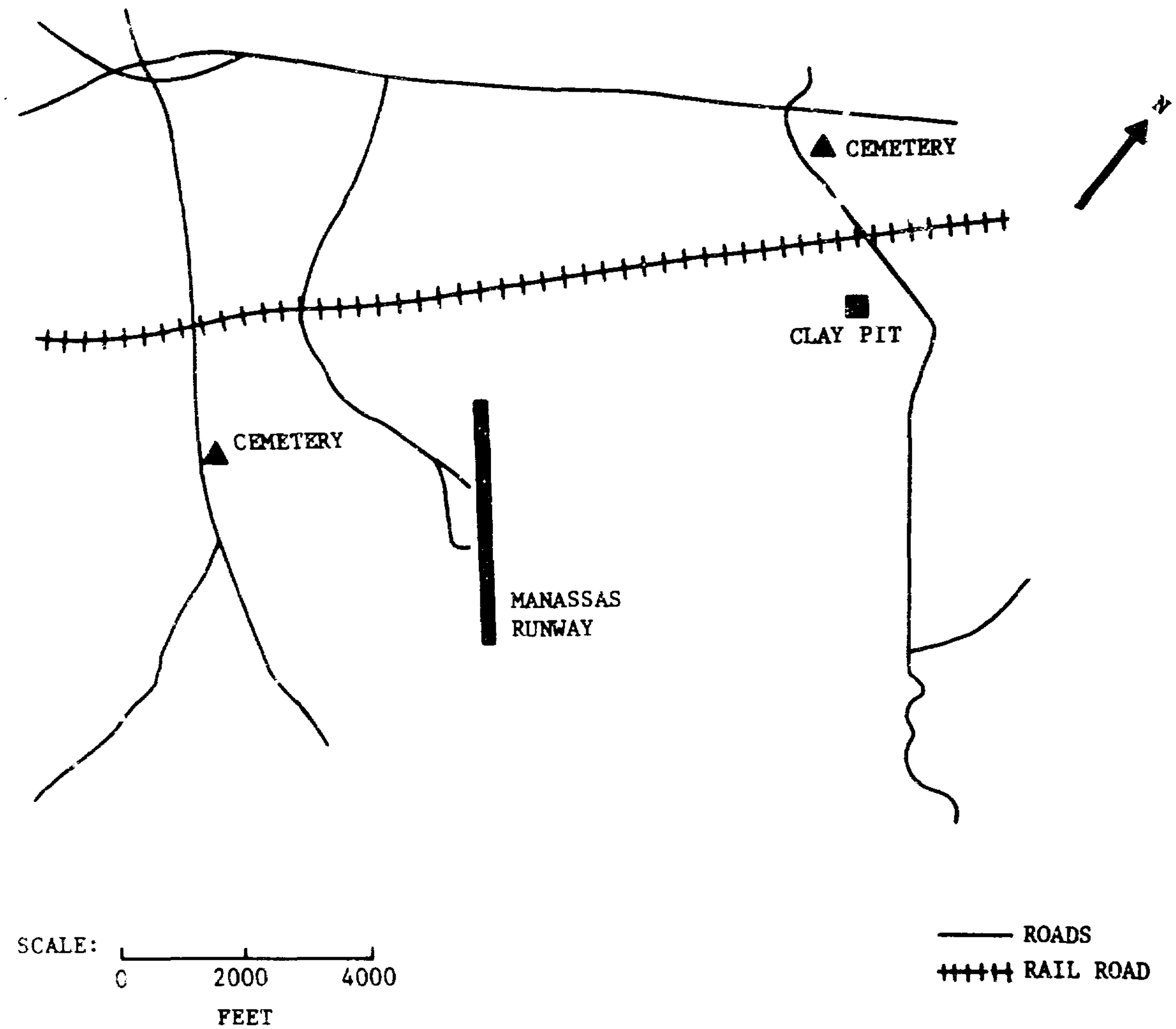


FIGURE 2-1
MANASSAS AIRPORT VICINITY

traffic. Two of the observers were stationed with surveying transits to be used for measuring speed and position on downwind.

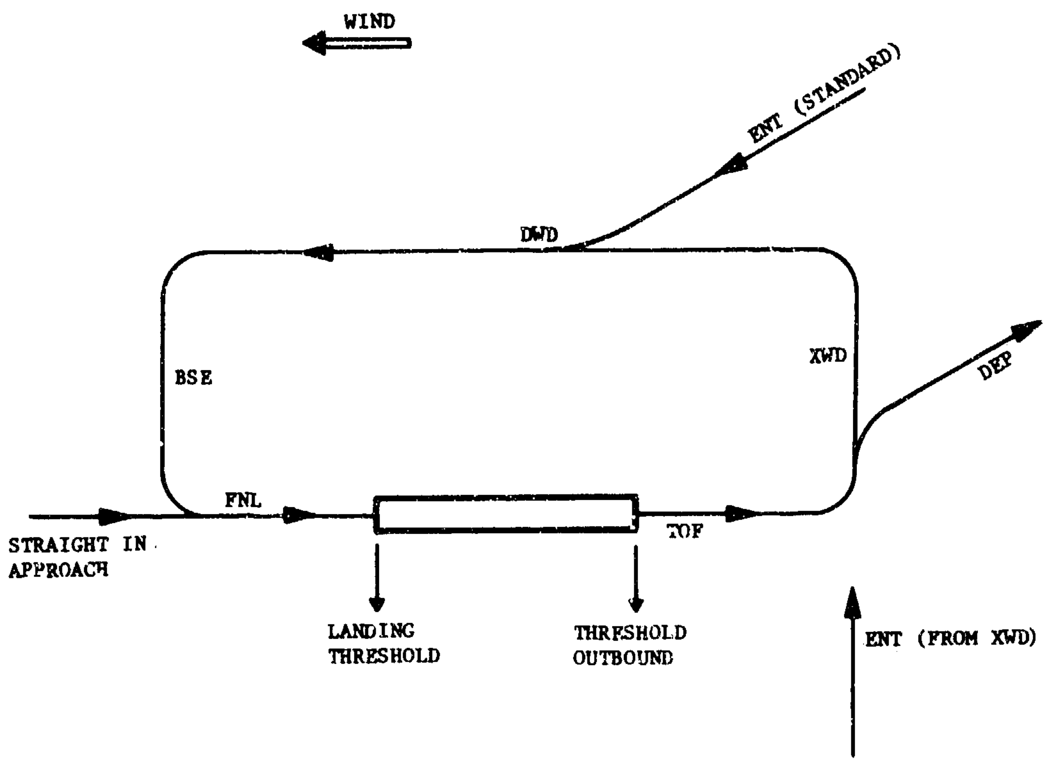
For each aircraft obtained visually in the airport area, a verbal description of its flight profile is recorded in real time on the cassette tapes. The descriptions are so made as to correlate exactly to the times that the events occur. The time intervals are measured by playing back the tapes at a later date. A list of possible events for traffic in this environment is shown in Table 2-2. The method anticipates that most aircraft in the vicinity of the runway follow a left-handed traffic pattern as shown in Figure 2-2. A flight profile is thus obtained for each aircraft in the system, a profile being made up of straight and turn sections, with time in each section known by observation. Since times of crossing each end of the runway (whichever is applicable) are known, these afford position fixes for the flight profiles. In addition, each aircraft on the downwind leg of the pattern has its speed, position and time at one point on downwind fixed by an optical transit-based method described in Appendix A. Thus, for all circulating aircraft we have the time information for the entire profile, plus we have three points in its flight (the two ends of the runway and one point on downwind) fixed in space.

Given the times for all sections of the profile if we assume speed and heading in each section, we can deduce x-y values of the flight profile. The assumed speed determines the size while the assumed headings determine the shape of the pattern. This may seem to lead to an infinite number of solutions. However, since we know three points in space and speed on downwind, the fit is not as free as it might appear. Only a certain range of combinations of speed and heading changes can fit the time profile. To begin with, patterns are assumed to be nearly rectangular, (unless otherwise observed) and reasonable speed profiles for changes in ground speeds are assumed. Then each aircraft is projected through each section. A process of trial and error is used to find a set of speed or heading changes such that the resulting x-y profile fits the three points known to belong to it. This fit (that contains the speed, heading and each section of the flight) is the first representation of the track in the process of data reduction. An altitude profile is then assumed for the track on the basis of any qualitative altitude observations and normal aircraft behavior. The entire profile is then converted into a 4 sec scan picture of the entire traffic. The resulting data set is tested for unreasonable, construction induced aircraft proximities. If an aircraft pair is found to be too close, changes in the fitted headings and speeds are made so as to adjust the tracks to better

TABLE 2-2

EVENTS OBTAINED BY OBSERVERS

- Time of lift off
- Time an outbound aircraft passes over the end of the runway at the takeoff end
- Time a landing aircraft passes over the landing threshold
- Time of touchdown
- Times of the beginning and end of all turns (e.g., begin turn to crosswind, end of turn to final, etc.)
- Time aircraft first acquired
- Any other events of interest that may occur for aircraft that don't fly a standard profile and a description of these events.



TOF - TAKE OFF LEG
XWD - CROSSWIND LEG
DEP - DEPARTURE (TO LEAVE PATTERN)
DWD - DOWNWIND LEG
BSE - BASE LEG
FNL - FINAL
ENT - ENTRY

FIGURE 2-2
LEFT HANDED VFR TRAFFIC PATTERN

represent the actual traffic behavior originally observed. The criteria for this cleaning operation are described in Appendix A. Estimates of the accuracy of the resulting model are provided in the next section.

2.4 Actual Experimental Conditions and Accuracy Estimates

Data for the low density model (MANASSAS-I) was gathered on Sunday, May 5, 1974 from 2:30 p.m. to 3:15 p.m. There was a gusty 20 knot crosswind from south-west with scattered clouds and more than 10 miles visibility. RWY 16 was in use. Only two observers were used. Transit measurements were not made and information on speed and position on downwind was therefore not available for MANASSAS-I.

Data for the high density model (MANASSAS-II) was gathered on Saturday, October 26, 1974 from 1:15 p.m. to 2:00 p.m. There was a 10 knot wind very nearly along the runway. The sky was clear. In short, it was excellent flying weather. RWY 34 was in use. The complete observation process described earlier was used for MANASSAS-II. The overall accuracy of the high density model is thus improved with respect to the low density model.

The overall accuracies within the pattern may be studied by simple geometrical methods reflecting the process of fit, for first order estimates. Intuitively speaking, all errors are largest about midway between those points known accurately, namely, the two ends of the runway and the point established precisely by the transit. The accuracy of the position information therefore depends upon the type of track and portion of the track recorded. If an aircraft does not land or lift off from the runway or cross the transit lines of sight on downwind, its position is known very poorly, based on judgment only. On the contrary, for a circulating aircraft (40% of the tracks), the position is known to within 1000' at all times since three points on the trajectory are known very accurately.

Appendix B contains a detailed error analysis. Estimates of the overall accuracies in MANASSAS-II are given in Table 2-3. The table shows that accuracies are different for different parts of the pattern. The overall expected value of the position accuracy is 850'. Position and speed on downwind are unknown in MANASSAS-I. Mean values for errors in MANASSAS-I are estimated to be twice as much as those for MANASSAS-II.

TABLE 2-3

ACCURACY ESTIMATES FOR MANASSAS-II (1σ VALUES)

WHERE APPLICABLE	VARIABLE	WORST CASE ERRORS (WHERE)*	BEST CASE ERRORS (WHERE)*	EXPECTED VALUE OF ACCURACY
Tracks for which transit measurements are available. (About 45 cases of circulating patterns and arrivals).	Position	1000' (XWD, BSE)	200' (TOF, FNL, DWD at threshold)	600'
	Speed	20 Knots (XWD, BSE)	4 Knots (DWD at threshold)	13 Knots
	Heading	15° (XWD, DWD, BSE)	5° (TOF, FNL)	11°
Entry before joining downwind (transit measurement available) and departures.	Position	3000' (farthest from runway)	200' (DWD at threshold, TOF)	1500'
	Speed	30 Knots (farthest from runway)	4 Knots (DWD at threshold)	15 Knots
	Heading	30° (farthest from runway)	15° (DWD)	22°
Aborting entries, overs and other tracks for whom no position fixes available.	Position	4000'	4000'	4000'
	Speed	30 Knots	30 Knots	30 Knots
	Heading	30°	30°	30°
OVERALL ACCURACY ESTIMATE	Position			850'
	Speed			14 Knots
	Heading			13°

* The pattern symbols are defined in Figure 2-2.

3. SUMMARY DESCRIPTIONS OF THE TRAFFIC

This section contains statistics on the behavior of air traffic near Manassas Airport as observed on the two days, MANASSAS-I on May 5, 1974, and MANASSAS-II on October 26, 1974.

3.1 Gross Traffic Mix

Table 3-1 contains an overview of the two models. Both models are of 45 minutes duration. MANASSAS-II has an hourly operations rate of nearly 150, more than 3 times that of MANASSAS-I. A total of 37 different aircraft use the airspace in MANASSAS-II, compared to 17 in MANASSAS-I. An aircraft in MANASSAS-II stays in the system about 50% longer than in MANASSAS-I.

On the average, there are five to six aircraft in the model at all times in MANASSAS-II - more than 3 times as many as in MANASSAS-I. Touch and Go's exist in both models and we see that the denser situation can create fairly long departure queues. The most dramatic effect of the denser traffic is seen in the phenomenon of aborting aircraft. About every sixth track* in MANASSAS-II is seen to exhibit some type of an abortive maneuver, such as resulting from an unsuccessful entry where the downwind traffic is such that the aircraft decides to leave the pattern. This phenomenon is discussed later in greater detail and has important consequences for the design of any automatic traffic control system.

Table 3-2 provides a detailed breakdown of airport operations. Landing and departure each contribute one operation. A touch and go contributes two operations. An over flight contributes one operation. We see that over 50% of the operations are accounted for by touch-and-go's.

Table 3-3 provides a breakdown of the types of tracks observed. 50% of all tracks in MANASSAS-II are of the circulating type. Thus, every second airborne aircraft is circulating in the pattern.

3.2 Order and Disorder in the Pattern: Effect of Traffic Density

One of the most striking features of MANASSAS-II is the existence of so many instances of abortive tracks. This is clearly related to its increased traffic density. We have a dual situation here. As the traffic density goes up, we expect that aircraft may start

* See Glossary

TABLE 3-1
SOME OVERALL TRAFFIC CHARACTERISTICS

VARIABLE	MANASSAS-I	MANASSAS-II
Duration of Model	45 minutes	45 minutes
Number of Operations in Model	33	111
Hourly Operations Rate Implied	43	148
Number of Distinct Aircraft in Model (Distinct Tail Numbers)	17	37
Average Duration of an Aircraft (a specific tail number) in Model	4.1 minutes	6.7 minutes
Average Number of Aircraft in Model at one time	1.6	5.6
Peak Number of Aircraft in Model at one time	5	9
Peak Number of Touch & Go per Aircraft	7	9
Peak Length of Departure Queue	1	6
Total Number of "Tracks"* Exhibiting Some Type of Abortive Maneuver	0	13
Total Number of "Tracks"* in Model	25	79

* See glossary for definition of "Track".

TABLE 3-2
OPERATIONS MIX

OPERATION TYPE		MANASSAS-I		MANASSAS-II	
		# In Model (45 minutes)	Implied Hourly Rate	# In Model (45 minutes)	Implied Hourly Rate
LANDING	Landing and leaving runway	8		7	
	Landing and joining departure queue	-		6	
	Landing and executing a touch-and-to	8		30	
	Unknown landing behavior	-		7	
	Sub-Total	16	21	50	67
TAKE OFF	From departure queue	8		14(4)*	
	From touch-and-go	8		30	
	Unknown takeoff behavior	-		2	
	Sub-Total	16	21	46(4)	61
OTHER	Go-arounds	-		3(2)*	
	Overs	1		5	
	Aborted on entry	-		7(7)*	
	Sub-Total	1	1	15(9)	20
TOTAL		33	43	111(13)	148

* Figures in parentheses are the number of operations of the total that are associated with an abortive maneuver.

TABLE 3-3
MIX OF TRACK* – TYPES

TYPE		Number of Tracks* In Model (45 min)	
		MANASSAS-I	MANASSAS-II
Circulating Patterns*		8	34
ARRIVALS	Coming to Land	8	14
	Aborting at Entry on Downwind	–	7#
	Performing Go-Around	–	1#
DEPARTURES	Off Crosswind	8	10
	Aborting on Downwind Near Base	–	4#
OVERS		1	5
UNKNOWN	Initial Tracks	–	3
	Initial Track Performing Go-Around	–	1#
TOTAL		25	79

* See Glossary for definition.

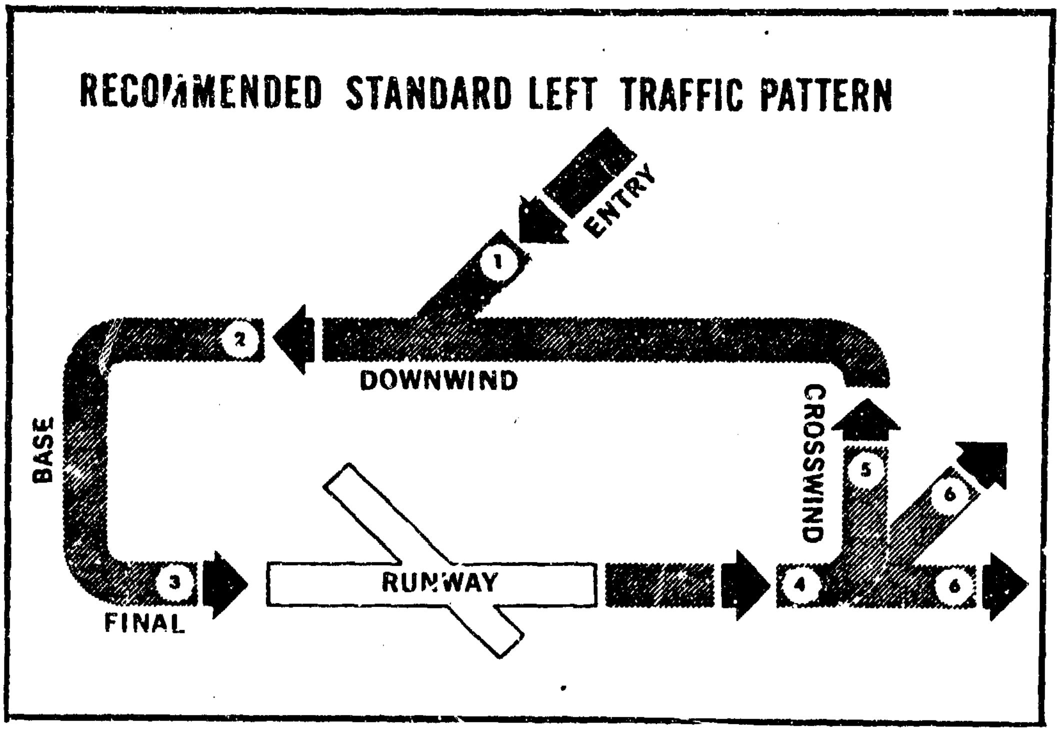
\# These tracks involve an abortive maneuver performed by aircraft. There are a total of 13 of these.

showing a greater orderliness in the pattern. If the traffic becomes too dense, however, aircraft may start breaking out of the pattern for reasons of lack of space or traffic hazards. It is of interest to any terminal air traffic control system to see how regular or orderly the behavior of aircraft in a typical terminal airspace is. In this section we delineate these characteristics of MANASSAS-I and MANASSAS-II.

Manassas Airport has no published traffic pattern contradicting the standard left hand traffic pattern normally flown by VFR aircraft at uncontrolled airports. The traffic pattern shown in Figure 3-1 is the FAA recommended standard traffic pattern, (Reference 8) and is taken here as a point of departure. An aircraft track conforming to this standard will be called "regular", one not conforming will be called "irregular". Thus, straight-ins and crosswind entries are irregular in our definition. Appendix C describes the various possible regular and irregular tracks.

Table 3-4 contains a detailed summary of all irregularities observed on both days of observation. We see that about 25% of all tracks exhibit some type of irregular behavior in both models, the proportion being slightly greater for MANASSAS-II, the higher density model. This count, however, includes those irregularities that are correlated with traffic hazard. The numbers in parenthesis in Table 3-4 are the irregularities that were apparently caused due to pilot action initiated in response to busy traffic conditions. Thus, an aircraft attempting to enter the pattern by a standard 45° entry may abort its entry by a right turn because of existing traffic on downwind in a position of threat or congestion. (There are 6 such instances in MANASSAS-II). Similarly, an aircraft well established on downwind, eligible for turning base after having crossed the threshold line, may decide to abort due to too many aircraft existing on base and/or final. This latter type of abort typically involved turns and simultaneous climbs. (There are four such instances in MANASSAS-II). The table shows that 17% of all tracks exhibit some such escape maneuver in MANASSAS-II.

When irregularities caused by pilot perceived traffic hazards are counted out, we find that the percentage of unnecessary or unexplainable behavior reduces in MANASSAS-II to 11%. This confirms our expectation that more standard behavior can be expected in higher density traffic.



1 ENTER PATTERN IN LEVEL FLIGHT, ABEAM THE MIDPOINT OF THE RUNWAY, AT PATTERN ALTITUDE.

2 MAINTAIN PATTERN ALTITUDE UNTIL ABEAM APPROACH END OF THE LANDING RUNWAY, ON DOWNWIND LEG.

3 COMPLETE TURN TO FINAL AT LEAST 1/4 MILE FROM RUNWAY.

4 CONTINUE STRAIGHT AHEAD UNTIL BEYOND DEPARTURE END OF RUNWAY.

5 IF REMAINING IN THE TRAFFIC PATTERN, COMMENCE TURN TO CROSSWIND LEG BEYOND THE DEPARTURE END OF THE RUNWAY, WITHIN 300 FEET OF PATTERN ALTITUDE.

6 IF DEPARTING THE TRAFFIC PATTERN, CONTINUE STRAIGHT OUT, OR EXIT WITH A 45° LEFT TURN BEYOND THE DEPARTURE END OF THE RUNWAY, AFTER REACHING PATTERN ALTITUDE.

FIGURE 3-1
FAA RECOMMENDED STANDARD TRAFFIC PATTERN

TABLE 3-4
IRREGULAR BEHAVIOR IN PATTERN AREA

TYPE OF IRREGULAR BEHAVIOR	SUBDIVISION and DESCRIPTION	Number of Instances in Model (45 minutes) MANASSAS-I	MANASSAS-II
Nonstandard Entries	Straight-Ins. Crosswind entries.	- 2	2 3
Standard Entries (Joining downwind on Entry)	Standard Abortion (right turn) on standard 45° Entry Non-Standard Abortion (left turn) on standard 45° Entry		(6) (1)
Departure	Small Left Turn off XWD Right Turn off Takeoff Leg Departure off DWD	1 1 1	1 - -
Downwind near base	Aborting by right turn on DWD near base Aborting by non-standard left turn on DWD near threshold (aircraft performed a 360° turn)	- -	(2) (2)
Take off	Turn to crosswind while still over the RWY	-	1
Landing	Go-around by small right turn and climb Go-around by climb only	-	(2) 1*
Over	Flight through airspace	1	1
Total of all irregular instances		6	22
% of Total tracks exhibiting irregular behavior		24%	28%
Total # of Tracks possibly related to some traffic hazard(1) (Escape behavior)		0	13
% of Total tracks exhibiting escape behavior		0	17%
Total # of tracks exhibiting unexplanable irregular(2) behavior		6	9
% of all tracks with unexplanable irregular behavior		[illegible]	11%

Notes

1. Numbers in parentheses represent instances that are most probably caused by traffic conditions (hazard, tedium, etc.)

2. "Unexplanable irregular" behavior refers to instances definitely not related to any traffic hazard conditions.

* A missed approach type of situation, presumably related to individual pilot's skill.

Another interesting aspect of orderliness in heavier traffic is the self ordering behavior of aircraft in pattern. A closer look at MANASSAS-II reveals that when aircraft on downwind are passing threshold in close time proximity, they generally line themselves up in sequence. We found 13 instances (pairs) where two aircraft were passing abeam the threshold within 20 seconds of each other. Of these, in three instances the trailing aircraft was already aborting its pattern on downwind. Of the remaining ten instances, in eight the trailing aircraft was within 1000 feet lateral spacing of the leading aircraft and the trailing aircraft was traveling at about the same or slower speed as the lead aircraft. This is clearly a self spacing behavior of aircraft.

The two exceptions were as follows. One involved a twin engine aircraft, executing a very wide pattern at a much higher speed. The second exception is an interesting aberrant case. The trailing aircraft passed abeam the threshold 6 seconds after the leading aircraft and was 1500 feet farther out on a wide downwind leg. The trailing aircraft then attempted to break the sequence by cutting ahead. The pilot regretted his actions later, for at the time of landing the originally leading aircraft was so close behind that the offending pilot elected to execute a go-around.

3.3 Sequence Behavior and Inter-Aircraft Times in MANASSAS-II

The previous section hints at aircraft generally establishing and maintaining some kind of a sequence in the downwind-base-final sections of the pattern. We explore this further here.

Assume the order in which aircraft pass abeam threshold on downwind as defining the sequence to land, regardless of how far out the aircraft is laterally on base leg. Figure 3-2 is a histogram of the number of aircraft that may be considered to be ahead in the landing order at the moment when an aircraft is passing abeam the threshold on downwind. Figure 3-2 shows that in MANASSAS-II, at least one and possibly as many as five aircraft are ahead waiting to land. On the average, there are 2.6 aircraft ahead. This number includes aircraft that may be aborting and those coming straight in. (For the straight-ins, an expected time to land was estimated).

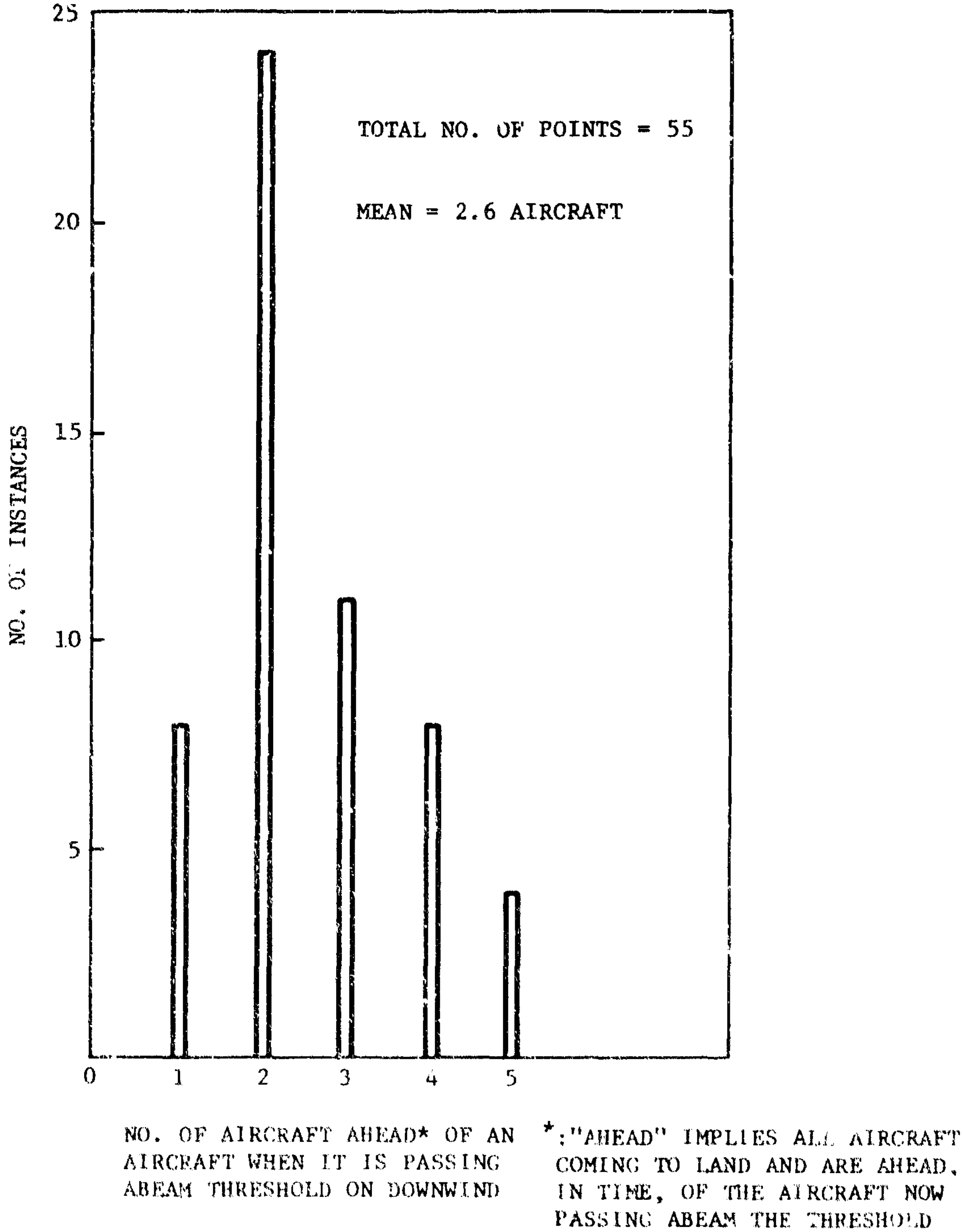


FIGURE 3-2
ACTIVITY IN THE BASE-FINAL REGION

In assisting the pilot in sequencing his landing in an automatic advisory system such as ATS, a message containing observed sequence may be provided. It is of interest to see if a simple sequence determination rule (such as that given above) is adequate, i.e., is the declared ordering maintained to landing. Table 3-5 summarizes the results. We see that with one exception, the sequence order is maintained in normal circumstances. The number to land may, however, be altered because an aircraft on downwind may abort after passing downwind beam threshold, or an aircraft may be coming straight in.

Figure 3-3 provides a histogram of inter-arrival times in MANASSAS-II. There is about one landing per minute on the average with half the inter-arrival intervals being betwen 25 and 30 seconds.

Figure 3-4 gives a histogram of inter-departure times. There is about one departure every minute.

3.4 Pattern Dimensions Statistics

This section summarizes major observations on pattern dimensions.

As discussed in Section 2, the speed and positions of aircraft on downwind when abeam the threshold are directly observed in MANASSAS-II. Figure 3-5 shows the histogram of speeds. About 75% of all aircraft are traveling at 90 $\pm$ 10 knots, although the total spread is from 60 knots to 150 knots. Figure 3-6 shows the histogram of position on downwind abeam the threshold. 75% of the aircraft are about 3/4 mile out on downwind.

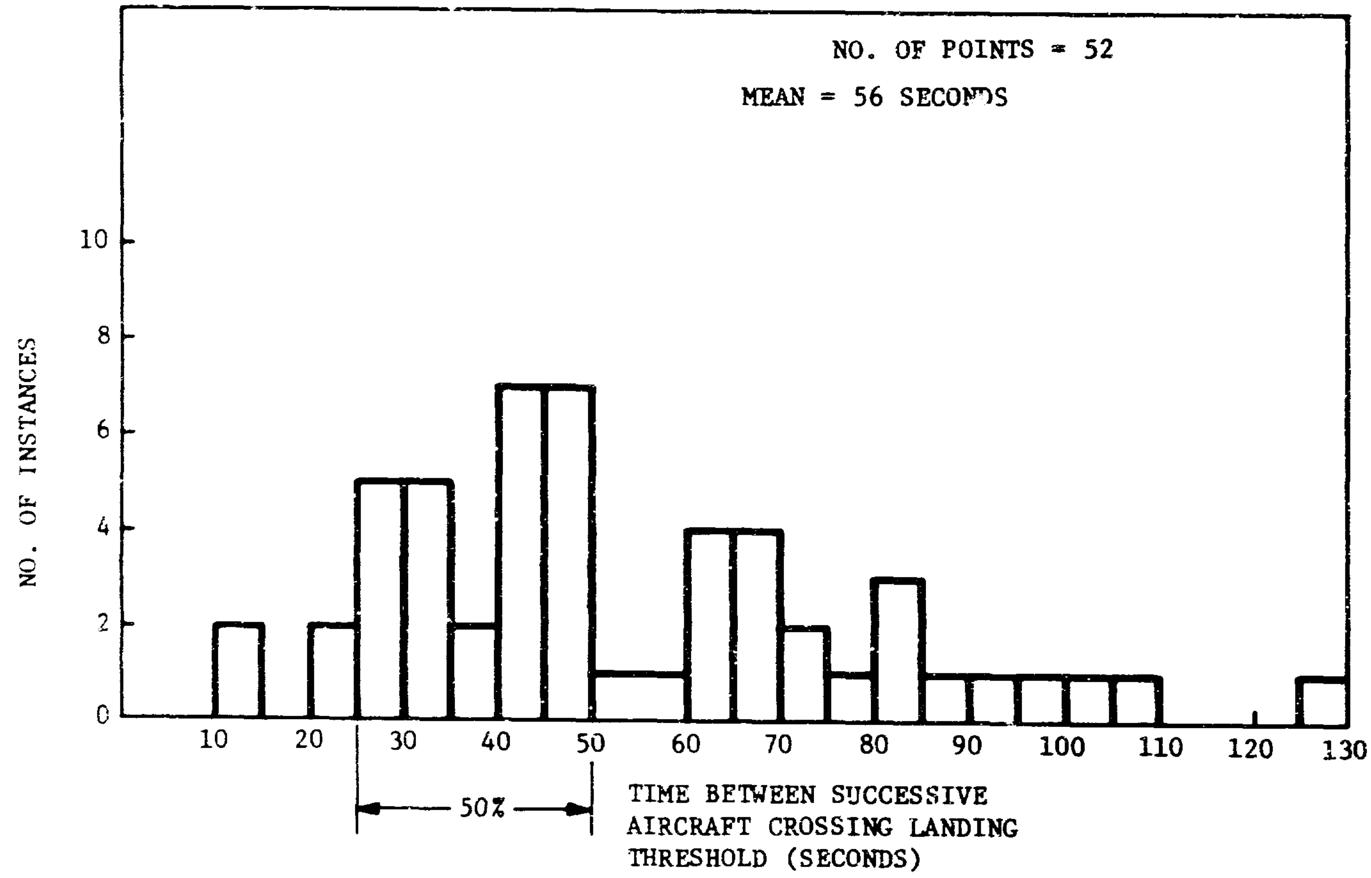
Although considerable spread both in speeds and downwind-offsets exists over the entire model, we have already seen (Section 3.2) that this does not happen randomly. Aircraft occuring closely in time are also clustered in space, moving at nearly equal speeds in trail-type formation.

The primary information obtained for both MANASSAS-I and MANASSAS-II was time of event information as described in Table 2-2. From this information, the time that each aircraft spends in the various sections of the pattern is directly obtained. This data effectively gives us pattern dimensions in time units, and is summarized in Table 3-6. This table provides average times in each section, as well as cumulative times from the beginning of each track. We note the following important information from this table.

TABLE 3-5
SUMMARY OF ALTERED SEQUENCE NUMBERS OF AIRCRAFT PASSING THRESHOLD ON DOWNWIND FOR MANASSAS-II

Instances of aircraft not landing (aborting on downwind after passing threshold on downwind).	9
Instances of aircraft coming straight-in to land.	2
Instances of two aircraft switching their sequence between passing threshold on downwind and crossing threshold to land.*	1
In all other cases, the sequence in which aircraft pass threshold on downwind is preserved to landing.	-

*In this case, trailing aircraft A cuts ahead of aircraft B. When on final, B is too close behind and A (the leading aircraft) was observed to go around.



NOTE: IN BOTH CASES OF $\Delta T \leq 15$ SECONDS, THE LEADING AIRCRAFT IS EXECUTING A GO-AROUND

FIGURE 3-3
INTER-ARRIVAL TIMES AT LANDING THRESHOLD IN MANASSAS-II

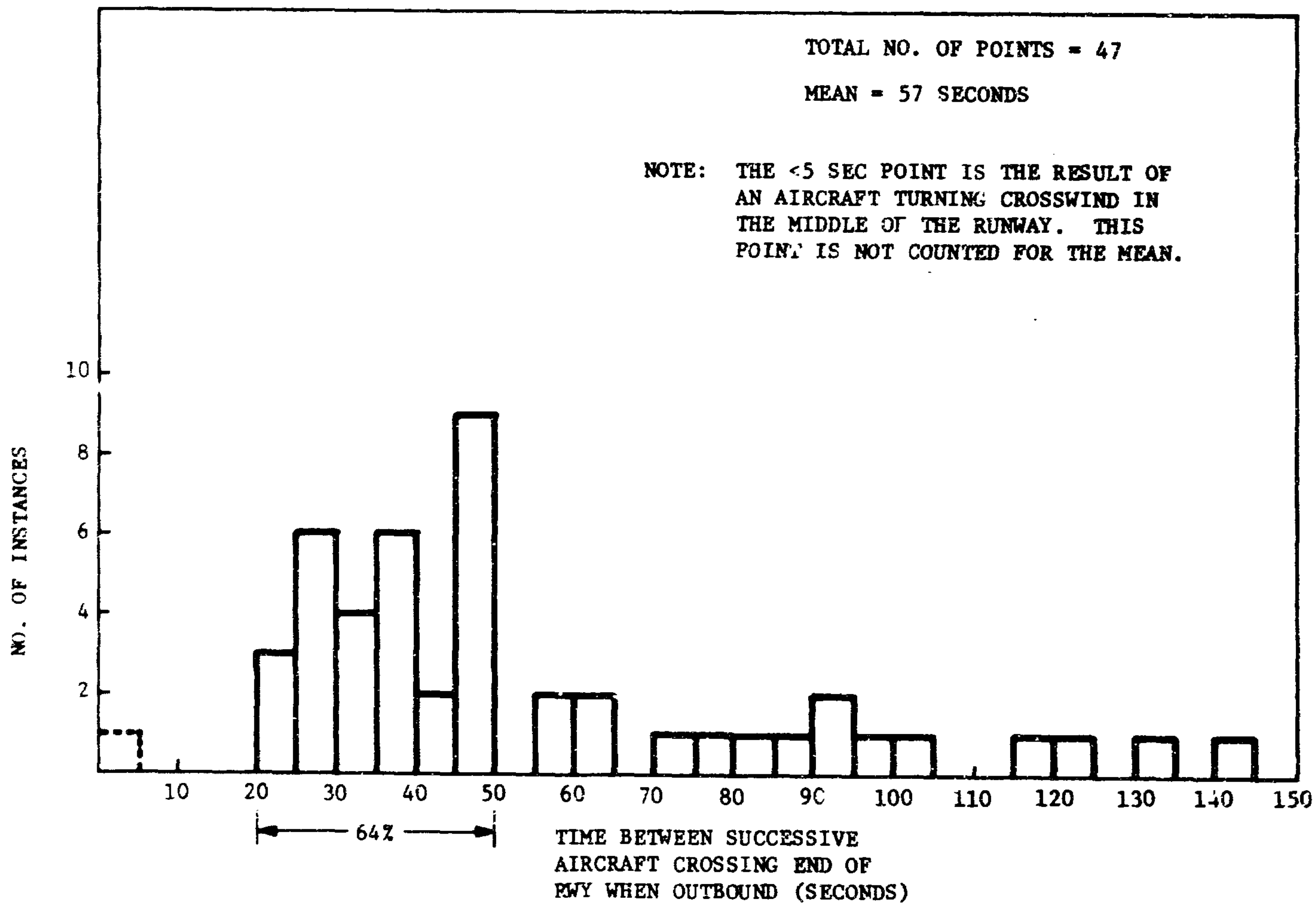
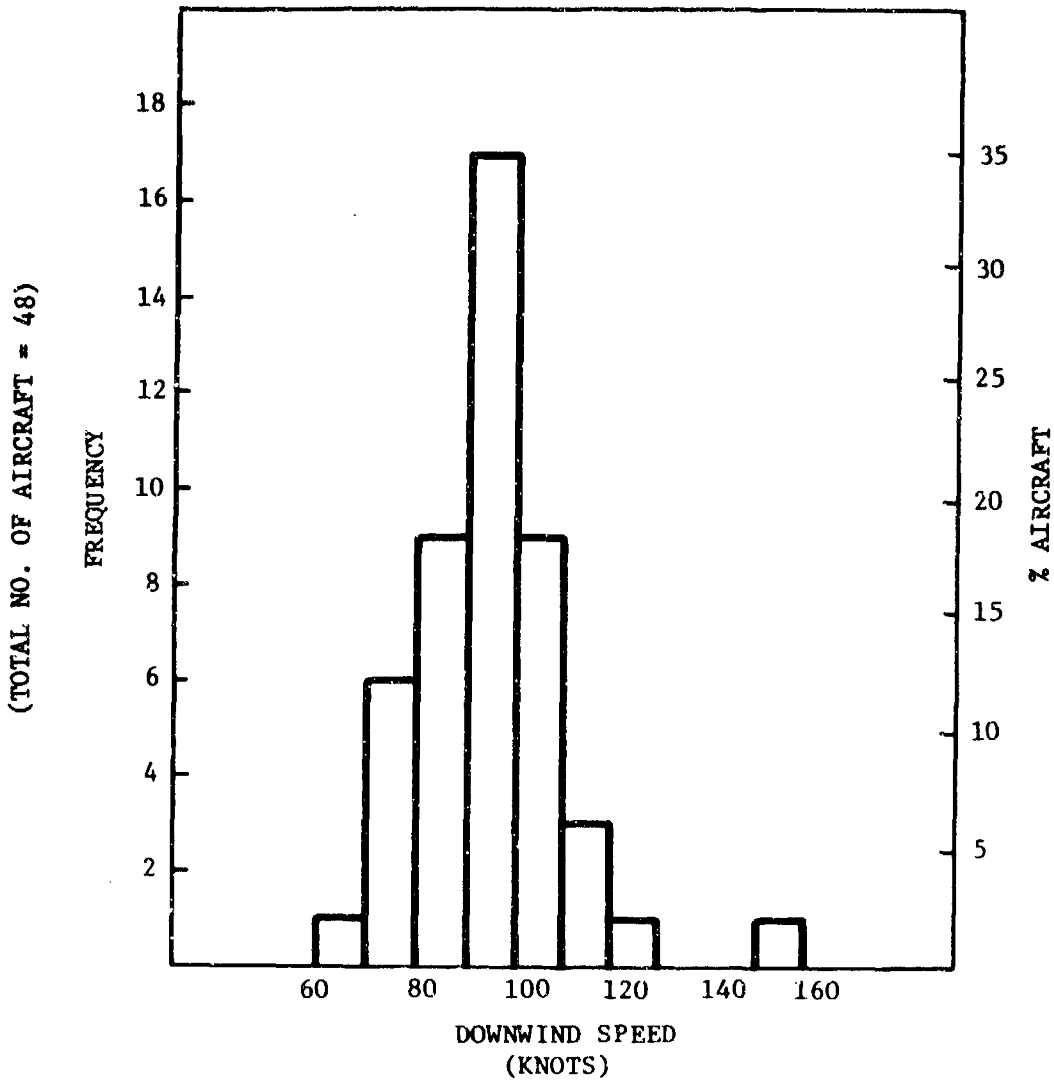
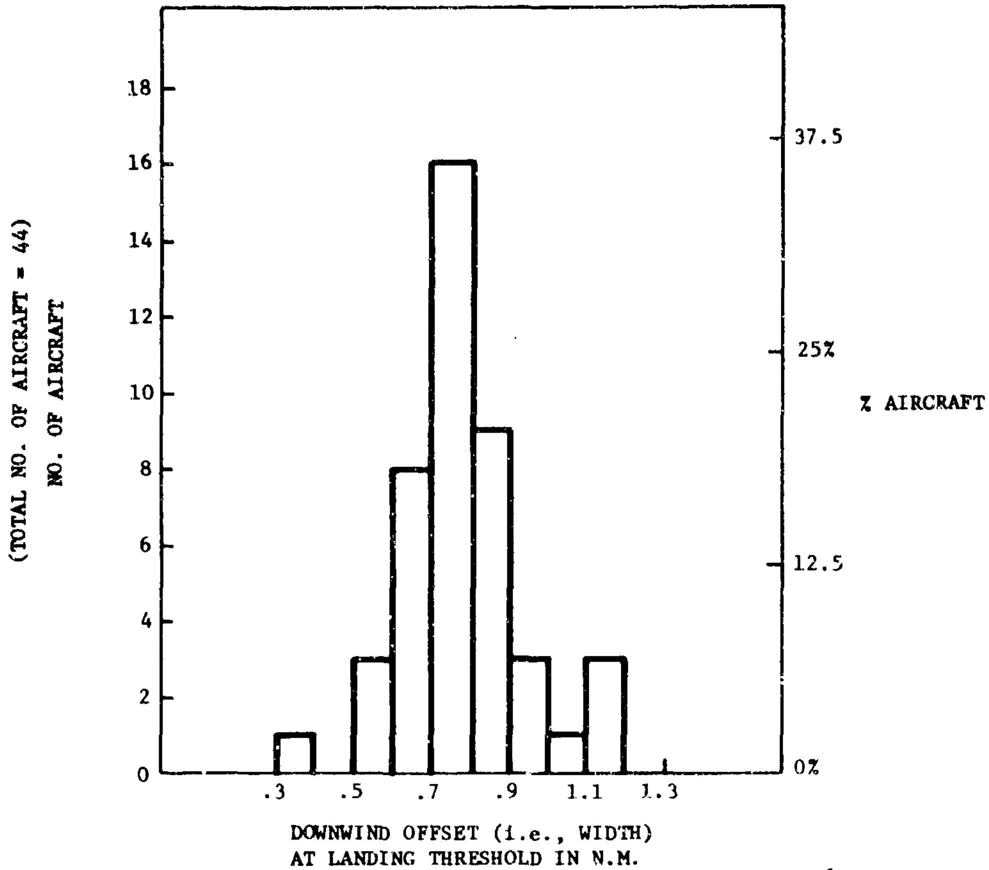


FIGURE 3-4
INTER-DEPARTURE TIMES IN MANASSAS-II
(TIME AT END OF RUNWAY)



ERROR ESTIMATES: 7% UNKNOWN MAXIMUM BIAS (AFFECTING ALL AIRCRAFT THE SAME WAY) + 4% RANDOM

FIGURE 3-5
DISTRIBUTION OF AIRCRAFT SPEEDS MEASURED ON DOWNWIND WHILE PASSING THRESHOLD IN MANASSAS-II



ERROR ESTIMATES: 7% UNKNOWN MAXIMUM BIAS (AFFECTING ALL AIRCRAFT THE SAME WAY) + APPROX. 4% (1σ)

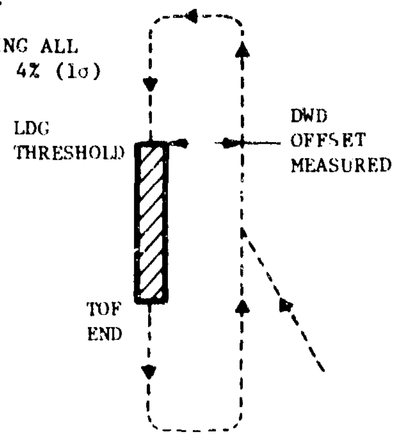


FIGURE 3-6
DISTRIBUTION OF DOWNWIND OFFSETS IN MANASSAS-II

TABLE 3-6
STATISTICS ON OBSERVED PATTERN DIMENSIONS IN TIME UNITS

TYPE OF TRACK (1)	SECTION (2)	MANASSAS-I				MANASSAS-II			
		TOTAL NUMBER OF TRACKS USED	TIME MEASURED FROM BEGINNING OF TRACK TO END OF SECTION (5)		MEAN AMOUNT OF TIME IN SECTION (SECONDS)	TOTAL NUMBER OF TRACKS USED	TIME MEASURED FROM BEGINNING OF TRACK TO END OF SECTION (5)		MEAN AMOUNT OF TIME IN SECTION (SECONDS)
			MEAN (SECONDS)	STANDARD DEVIATION (SECONDS)			MEAN (SECONDS)	STANDARD DEVIATION (SECONDS)	
CIRCULATING PATTERN	TOF	8	30.6	6.2	30.6	34	25.5	8.6	25.5
	XWDT		37.7	6.7	7.1		35.8	9.3	10.3
	XWD		56.9	9.9	19.2		56.7	13.7	20.9
	DWDT		64.3	10.0	7.4		66.9	14.0	10.2
	DWD		146.0	12.2	81.7		153.9	16.9	87.0
	BSET		157.0	12.4	11.0		164.1	17.3	10.2
	BSE		179.9	13.7	22.9		199.3	23.4	35.2
	FNLT		192.3	16.2	12.4		207.5	23.3	8.2
	FNL(6)		230.3	17.3	38.0		268.4	30.9	60.9
ARRIVAL (3)	ENT	8	10.7	21.0	10.7	13	28.2	27.0	28.2
	DWET		16.1	22.0	5.4		37.2	26.5	9.0
	DWD		60.9	32.5	44.8		116.7	48.1	79.5
	BSET		73.2	33.9	12.3		130.9	47.4	14.2
	BSE		104.3	37.7	31.3		174.3	40.1	43.4
	FNLT		112.7	36.0	8.4		183.7	41.8	9.4
	FNL		149.1	32.5	36.4		246.2	46.0	62.5
DEPARTURE (4)	TOF	7	31.1	8.7	31.1	10	25.2	12.9	25.2
	XWDT		38.1	9.9	7.0		36.8	13.3	11.6
	XWD		65.6	28.6	27.7		50.7	16.0	13.9
	DEPT		71.0	27.1	5.2		60.1	14.8	9.4
	DEP		110.7	21.9	39.7		96.3	15.9	36.3

NOTES:
(1) See Glossary for definition
(2) See Glossary for definitions. (Thus, XWDT = turn to crosswind, etc.)
(3) This includes crosswind entries, 2 in MANASSAS-I and 3 in MANASSAS-II. Straight-ins are not included, nor are aborting aircraft. Each track begins when aircraft is first acquired in airspace.
(4) Irregular departures, such as those aborting on downwind, are not included. Each track ends when aircraft last observed in airspace.
(5) These are cumulative times within the track. If times spent in sections were statistically independent of each other, the standard deviations would be monotonically increasing. Clearly this is not always so.
(6) This row yields the average time for making a complete circulating pattern. For MANASSAS-I, this is 230.3/60 = 3.8 minutes. For MANASSAS-II, this is 268.4/60 = 4.5 minutes.

Most turns are seen to be about 10 second in duration. This would imply about a 9°/sec turn rate when turning in the pattern.

The straight line part of takeoff, crosswind and base sections are all about 30 seconds or less in duration. The crosswind section is often only about 20 seconds in duration. In contrast, the downwind section is about 90 seconds long. Minute-long finals are seen in the high-density model. In MANASSAS-I, shorter finals are seen.

About 15% of the time in the traffic pattern is spent in turns. This is an important characteristic of the traffic from the point of view of collision avoidance systems, which usually assume straight line flying.

Figures 3-7 and 3-8 give the average pattern dimensions for MANASSAS-I and MANASSAS-II respectively. The uncertainties in track headings and speed variations around the pattern result in uncertainties in these dimensions, as already summarized in Table 2-3. On the average, these dimensions are accurate to within 1000 feet (1σ).

Figure 3-8 also identifies the positions where abortive maneuvers were estimated to have started in MANASSAS-II. Most abortions, whether of aircraft trying to enter the pattern or of aircraft already within the pattern (those who took off from the runway) occur on downwind before coming abeam the threshold, although one escape maneuver begins on downwind way down near the base region.

3.5 Aircraft Physical Characteristics

There have been suggestions in past research on automated traffic services for unattended airports, that aircraft be identified to each other by their physical appearance, by voice communication.

Table 3-7 summarizes observed physical characteristics of air-borne aircraft in MANASSAS-I and MANASSAS-II. The characteristics in question are the color of the aircraft and wing-type (High wing or Low wing). When such characteristics were observed, most of the aircraft were seen to have the standard colors of either blue and white or red and white. No information on the type of aircraft make and model was recorded.

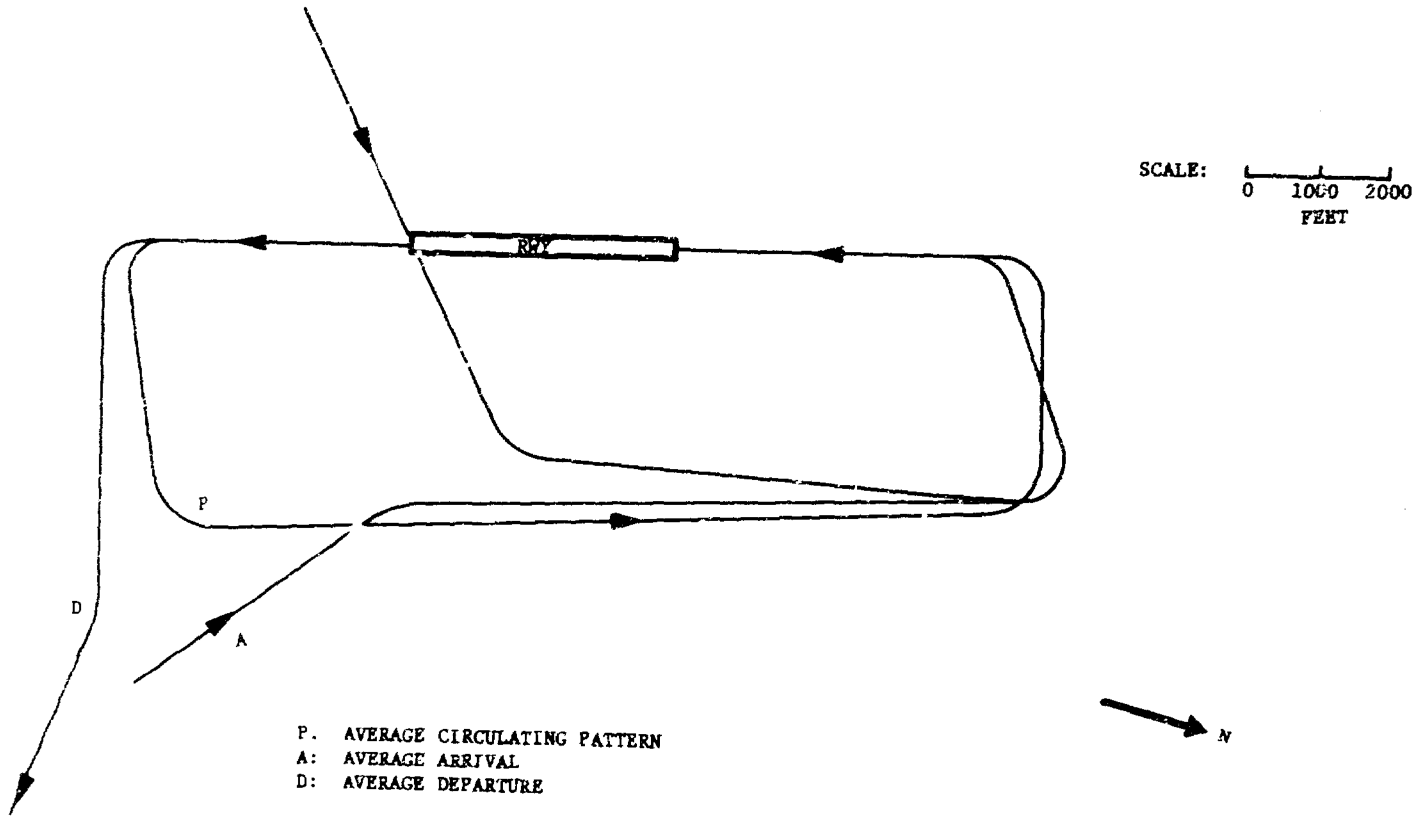


FIGURE 3-7
AVERAGE PATTERNS IN MANASSAS-I
(SOUTH OPERATIONS)

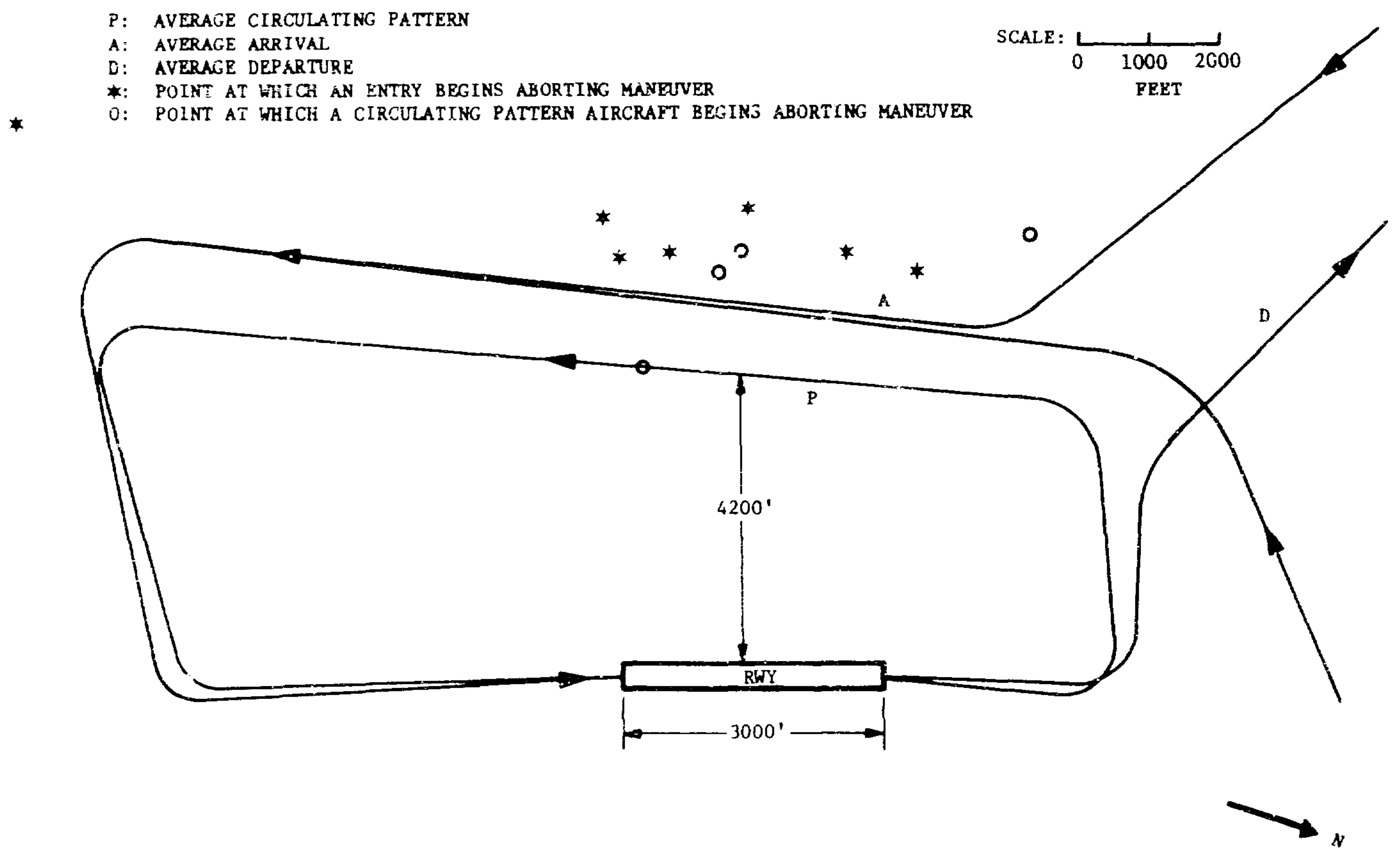


FIGURE 3-8
AVERAGE PATTERNS IN MANASSAS-II
(NORTH OPERATIONS)

TABLE 3-7
PHYSICAL CHARACTERISTICS OF AIRCRAFT

	High Wing	Low Wing	Other	Unknown	Total
Blue and White	9	2	1	1	13
Red and White	3	4	-	3	10
Gold	1	1			2
Orange				1	1
Tan		1			1
Mostly White		1			1
Unknown	1	6		19	26
Total	14	15	1	24	54

*Numbers are totals for both models together.

4. ALARM RATES

The goal of this section is to study the feasibility of collision detection logics in terms of alarm rates in the pattern environment using the models described in preceding sections. An analysis of the performance of several collision detection logics applied to these models is presented. For the purposes of this analysis, position and velocity information is assumed to be available in "perfect" form as provided by the models. The effects of surveillance errors and tracking errors on the performance of the logics is not addressed.

Let us recall that in MANASSAS-II, 13 of the tracks are characterized by some type of an abortive maneuver on downwind, related to pilot's perception of existing traffic hazard (collision danger) or a traffic situation such as an excessively long downwind leg causing a long final. An intelligent system may therefore be expected to issue alerts on some of these situations. The performance goal in this terminal environment is therefore no longer the reduction of alarms to zero. Rather, we would expect to minimize the total frequency of alarms, given that the true hazards are alerted. In Section 4.1, system alarm rates are studied, while in Section 4.2, the mix of true and false alarms is analyzed. The analysis is carried out for four different logics (designated A,B,C and G) representative of airborne and ground based systems. For each logic the effect of parameter threshold values, and traffic density is studied. Finally in Section 4.3, the effect of airspace region (e.g., entry region versus final approach region, etc.) is studied.

4.1 Conflict Logics and Parameter Sensitivities

The simple airborne collision avoidance (ACAS) systems such as those designed by RCA, Honeywell or McDonnel-Douglas make use of measured values of separation (range), and derived values of range rate and altitude difference between aircraft as well as the vertical speed of the subject aircraft. (See Reference 5). Relative bearing between aircraft is not measured. The parameter τ (tau) defined as the ratio of range to range rate is used as a measure of time to collision for non-maneuvering aircraft. A ground based system [1, 3, and 4] or an advanced airborne system [10] has access to the vector velocities of each aircraft. Therefore, in addition to the parameters mentioned above, projected miss distance and relative bearing information can be obtained. It will be interesting to compare performance of each class of system.

Conflict detection logics act on pairs of aircraft. Let:

R = Relative Range between two aircraft in nmi

τ = (Range)/(Range Rate) = $\frac{R}{dR/dt}$ in seconds

Z = altitude difference between aircraft in feet

MD = projected minimum miss distance between aircraft in nmi

Let R_C, τ_C, Z_C and MD_C represent the threshold values for these variables.

We consider four logics representative of airborne and ground based collision avoidance systems.

The logics are given by the following expressions, where an alarm is issued when the expression is satisfied:

Logic A: $(\tau \leq \tau_C | R \leq R_C)$ & $Z \leq Z_C$

Logic B: $(R \leq R_{C1})$ & $Z \leq Z_C$

Logic C: $((\tau \leq \tau_C$ & $R \leq R_{C2}) | R \leq R_C)$ & $Z \leq Z_C$

Logic G: $((\tau \leq \tau_C$ & $MD \leq MD_C) | R \leq R_C)$ & $Z \leq Z_C$

Logic A is the nominal ACAS detection logic. It alerts aircraft based on a tau-criterion to detect collision danger. In addition, it uses the range criterion to alert aircraft with low closing rates which are very near each other. Logic B is the range only logic essentially reflecting proximity warning. To encompass sufficient look ahead time in high closure rate geometries, this logic can issue a large number of alerts to nearby aircraft not really in conflict geometries. Logic C is an effort to reduce the alerts that may be issued by A or B within the constraints of a simple airborne system which cannot compute projected miss distances. It introduces a range cut off R_{C2} ($R_{C2} > R_C$) with the tau criterion. Logics A, B and C can thus be realized by a simple ranging and altitude telemetry form of airborne system. They can, of course, also be realized by a ground based system. Logic G is the most descriminating logic of the four logics described. It uses a projected miss distance test and hence can only be realized by a ground based system or perhaps an advanced airborne system providing vector data. Many variants of logic G, utilizing time to closest approach, modified-τ, etc. are conceivable and exist in the literature. However, at small look ahead times and miss distances, these become nearly equivalent.

The following nominal threshold values have been used in this analysis:

τ_C = 20 seconds (Warning Time)

R_C = 0.2 nmi (Immediate Range)

R_{C1} = 0.3 nmi (Range Cutoff)

R_{C2} = 0.4 nmi (Range Truncation on τ)

MD_C = 0.2 nmi (Miss Distance)

Z_C = 500 feet (Relative Altitude)

Figure 4-1 shows the sensitivity of alarm rates to the tau-threshold in MANASSAS-II. Logic A which is the basic tau-logic, is seen to be quite sensitive to the tau-threshold value. Logics C and G which impose tighter limit conditions, are less sensitive to the tau value. Selecting a tau threshold is a dual process, of yielding low enough alarm rates and providing large enough lead times to pilots for whatever correcting action may be necessary. The latter consideration is outside the scope of this paper. However, Monte Carlo studies of the lead time value indicate about 20 seconds effective time at alarm initiation to be adequate in the pattern [9]. We see that Logic G is able to provide rates of less than 20 alarms per hour for a tau threshold of 20 seconds.

Figure 4-2 shows the sensitivity of alarm rates to the range threshold. Logics A and B, which issue an alarm whenever the range threshold R_C is violated are seen to be very vulnerable to increasing the threshold value. For these Logics, at a threshold of 0.4 nmi (2400 feet), we are declaring a conflict every minute in MANASSAS-II. Although Logics B and C can provide low alert rates at 0.2 nmi threshold, such a low threshold is probably unusable by itself since in geometries of higher closing rates, it would mean very low lead times (6 sec at a track crossing angle of 90° for two aircraft at 105 & 75 knots).

A vertical threshold of 500 feet has been used in both figures above. Figure 4-3 shows that only a 20 to 30% reduction is possible with a tighter 200 feet vertical threshold. The effect of the vertical threshold is not very significant on alarm rates. There is, of course, considerable altitude correlation in the traffic pattern and the result is consistent with this characteristic.

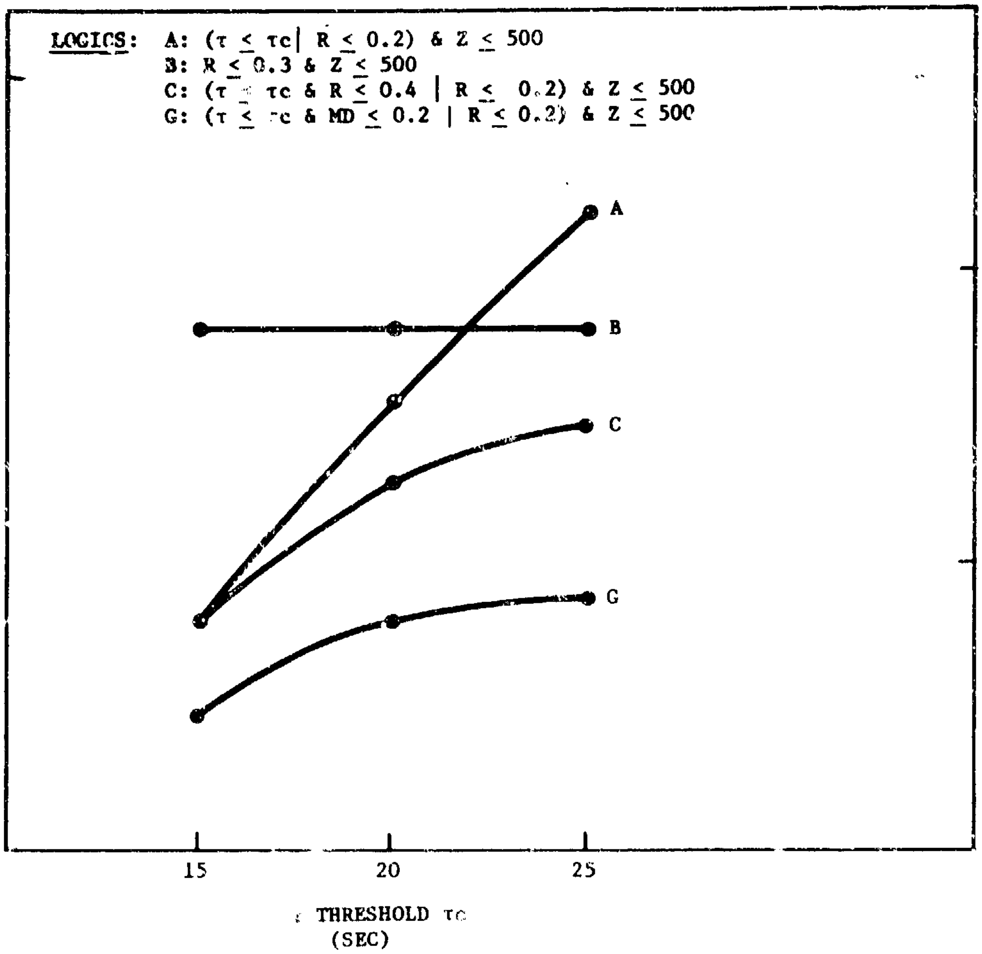


FIGURE 4-1
EFFECT OF TAU THRESHOLD ON ALARM RATES IN MANASSAS-II

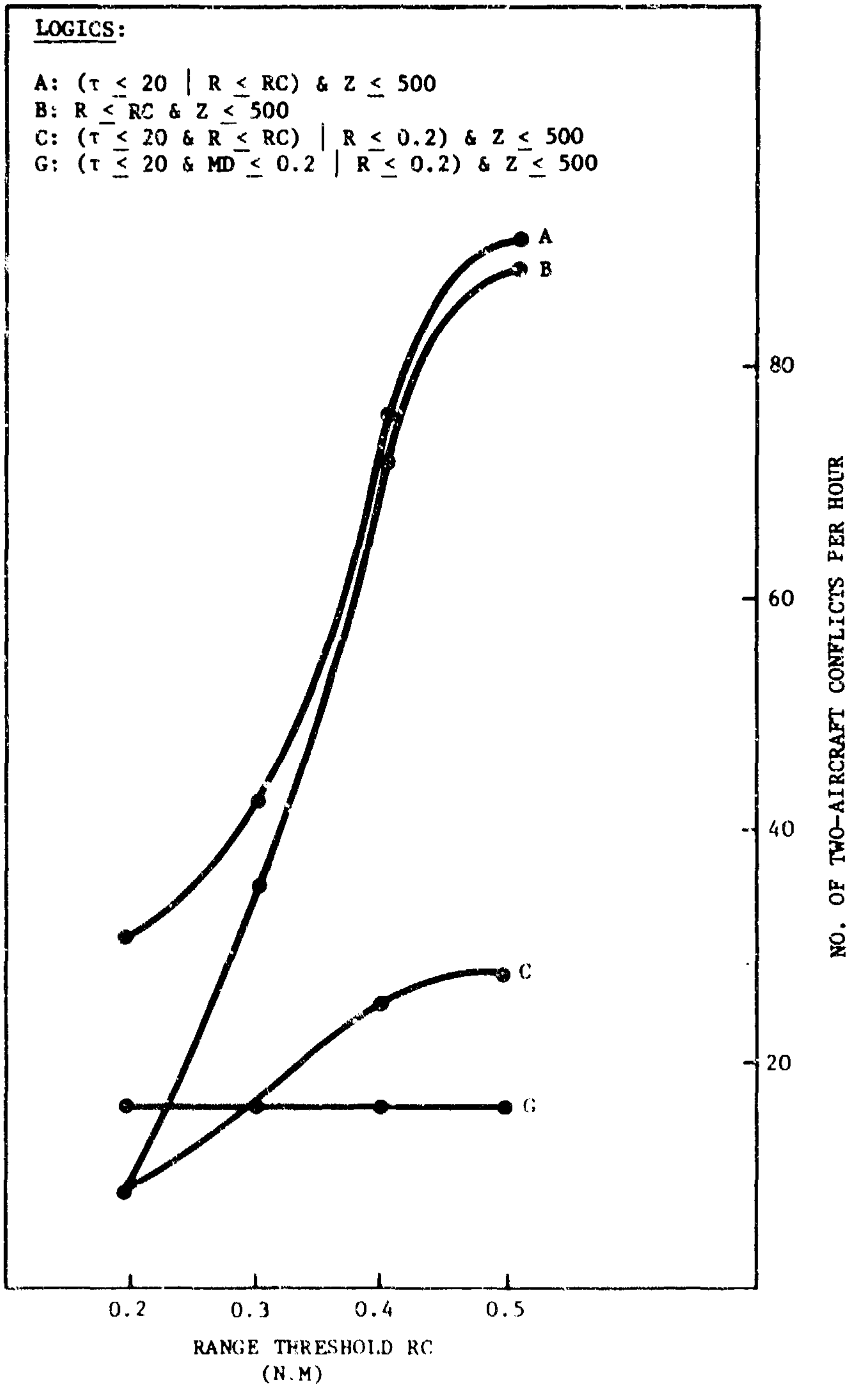


FIGURE 4-2
EFFECT OF RANGE THRESHOLD ON ALARM RATES FOR MANASSAS-II

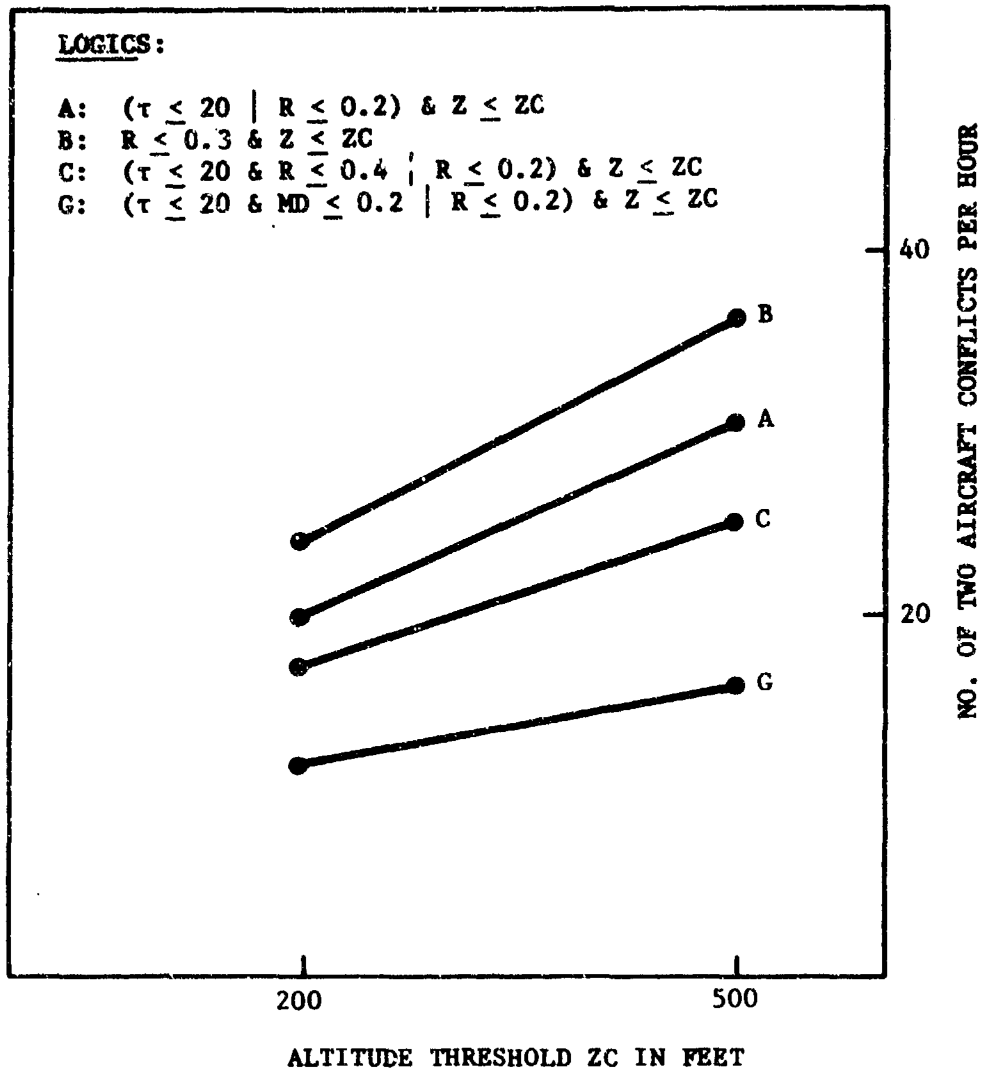


FIGURE 4-3
EFFECT OF ALTITUDE THRESHOLD ON ALARM RATES FOR MANASSAS-II

Figure 4-4 compares alarm rates for the two models, MANASSAS-I and MANASSAS-II. MANASSAS-II traffic is three times as dense as MANASSAS-I. It has nearly nine times as many alarms for any logic - fine fit for the conjecture that conflicts go up as the square of the density. This means that the alarms rate per operation at low density is about a third of that for high density. Thus, the system could use larger detection parameters at low traffic densities and still maintain the same alarm rate per operation as for higher density traffic. By using larger detection parameters, the system would be giving alerts at farther distances and earlier times. This many be of value in a low density flying environment where one may expect aircraft not to be flying in as well organized or vigilant a fashion as in higher density traffic.

Table 4-1 shows some statistics on alarms as seen by the individual pilot. It says, that for any of the three ACAS-type logics, (A,B,C) there is a 60% probability that if I conduct a flight in MANASSAS-II (whether a single arrival or multiple touch and goes), I will be declared to be in conflict at least once in my use of the airspace. This same value is 37% for the ground based Logic G. A more normalized number is provided by the percentage of tracks declared in conflict at least once. (A track is the smallest logical flight an aircraft may make in the pattern airspace. The same aircraft may contribute several tracks - e.g., as many as 10 circulating patterns in MANASSAS-II. See Appendix C for definitions.) For Logics A and B, every time I fly one complete track I have about a 50% chance of getting an alert sometime in my flight. This reduces to 25% for the ground-based Logic G. Finally, for Logics A, C and G, when I am in conflict, I may expect to stay in the conflict condition for about 8 to 10 seconds. For Logic B, this value is much larger, 22 seconds, because of densely packed in-trail situations in the traffic.

The fact that aircraft are fairly closely packed in the 0.3 to 0.5 nmi immediate relative range zone is seen in the sensitivity of alarm rates to range threshold in Figure 4-2. This feature has important consequences for airborne systems. Figure 4-5 shows the probability that a two aircraft conflict (as detected by any one of our logics) is actually part of a larger, multi-aircraft conflict. A multi-aircraft conflict is simply an aircraft cluster greater than two in which each aircraft is in conflict with at least one aircraft. There are no multi-aircraft conflicts with the airborne C and ground based G logic. There are many multi-aircraft conflicts for Logics A and B. For the range only Logic B, at 0.5 nmi threshold, 50% of all two

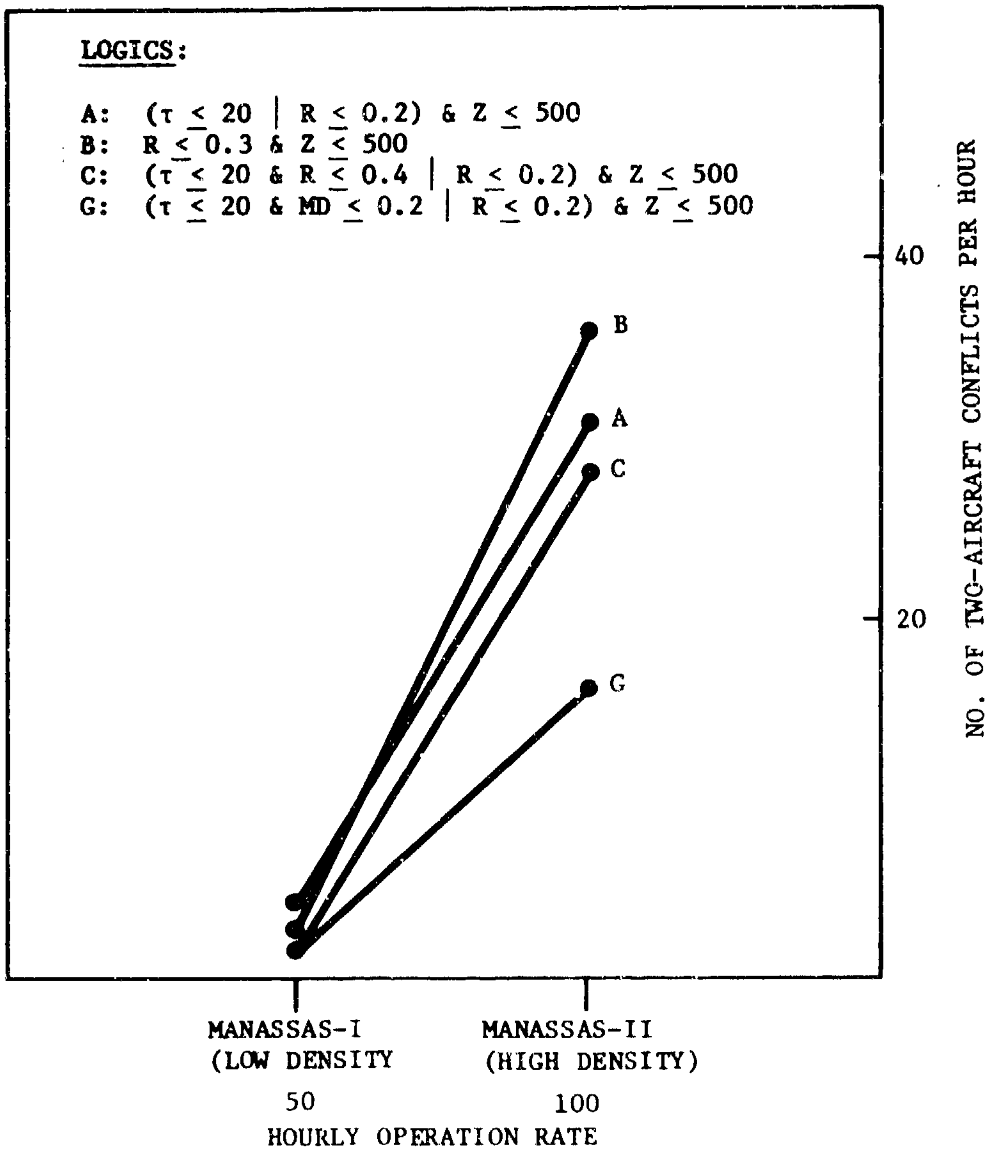


FIGURE 4-4
EFFECT OF TRAFFIC DENSITY ON ALARM RATES

TABLE 4-1
SOME COMPARISONS OF DETECTION LOGICS FOR NOMINAL PARAMETER VALUES FOR MANASSAS-II

	A $\tau \leq 20 \mid R \leq 0.2$	B $R \leq 0.3$	C $(\tau \leq 20 \& R \leq 0.4)$ $\mid R \leq 0.2$	G $(\tau \leq 20 \& MD \leq 0.2)$ $\mid R \leq 0.2$
% OF FLEET IN CONFLICT AT LEAST ONCE	60	60	60	37
% OF TRACKS IN CONFLICT AT LEAST ONCE	44	48	39	25
AVG DURATION OF CONFLICT IN SECONDS	9.5	22	8	10

Vertical Threshold = 500 Feet

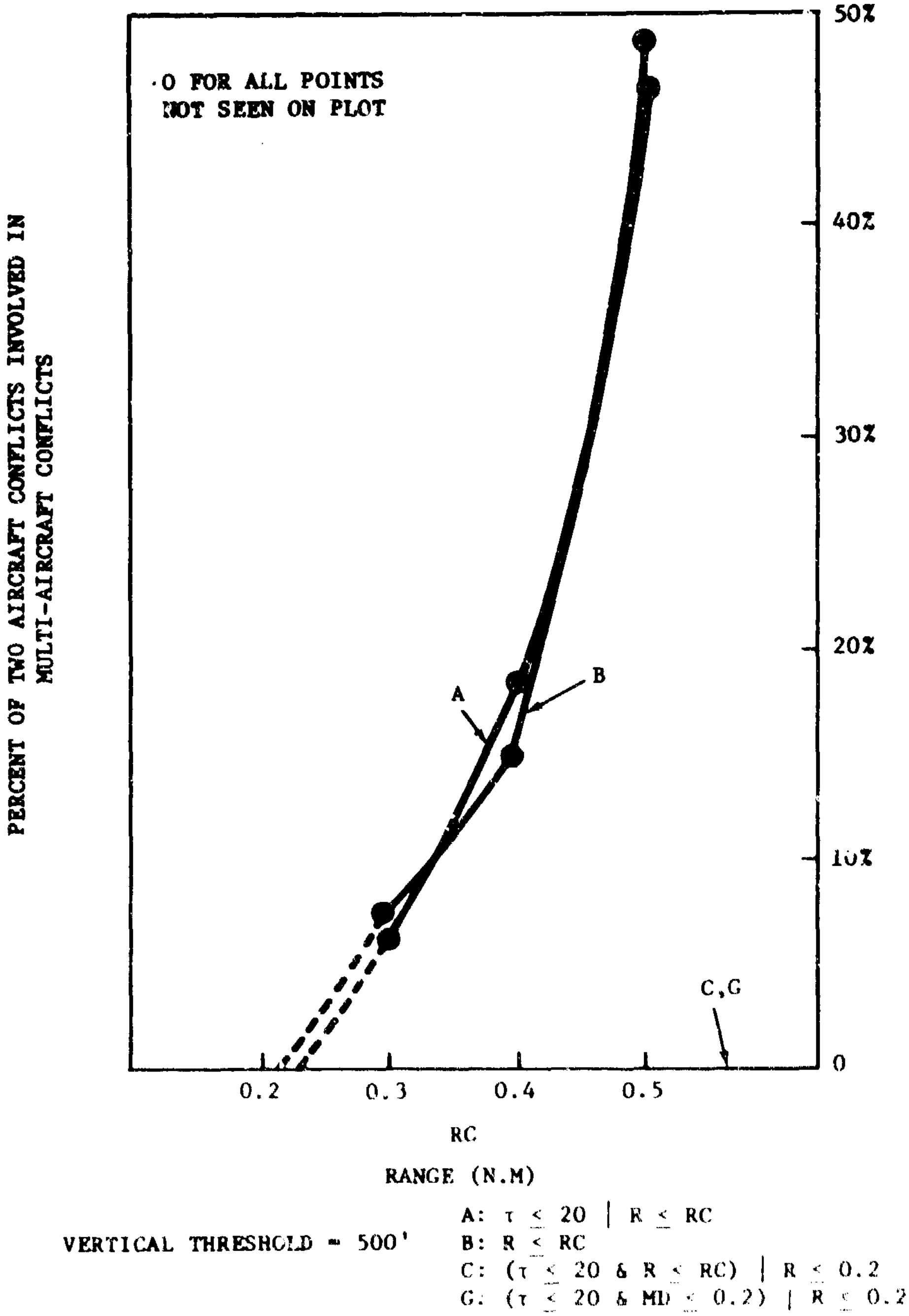


FIGURE 4-5
EFFECT OF IMMEDIATE RANGE THRESHOLD ON THE INCIDENCE OF MULTI AIRCRAFT CONFLICTS IN MANASSAS-II

aircraft conflicts are involved in a multi-aircraft conflict. This same number is 15% for a 0.4 nmi threshold for that logic.

Suppose an airborne system detects two aircraft in conflict using any of the logics A, B or C as specified in Figure 4-5, with range threshold 0.3 nmi. Suppose the system sounds an alert for both pilots involved to bring to their attention the fact that each is in conflict (with the other), but suppose that the system gives no bearing information. Both pilots would therefore look around to identify the other aircraft of the conflict pair. However, for at least one of the aircraft in the conflict pair, there is a 50% probability that we have at least one other aircraft (other than the conflict aircraft) within 0.5 nmi of it. (There is a 15% probability that there is another aircraft, other than the conflict aircraft, within 0.4 nmi.) In flight, the exact estimation of distance and conflict geometry is difficult and the pilot may identify this other aircraft 0.5 nmi away as the threat aircraft and not even try to locate the true threat (i.e., the threat detected by the logic being used).

In a ground based or advanced airborne type system, directional information could be provided with an alert. This would eliminate the potential confusion discussed above.

4.2 True and False Alarms

We have mentioned earlier that conflict alerts are in fact quite appropriate in MANASSAS-II. There are times when some observed aircraft themselves appear to have considered their course hazardous and made abortive maneuvers. About 17% of tracks in MANASSAS-II are related to such abortive maneuvers. Detecting such instances by an automatic system can therefore be considered "true" detection. If a logic declares a conflict involving an escaping aircraft within close temporal proximity preceeding or following its maneuver, the alert is defined to be a "true" alert. Of these true alerts, those detections that are made within 12 seconds (i.e., 3 scans) ahead of the time of actual manuever are defined as "predictive alerts". (It is predictive in that it preceeded the pilot's observed maneuver. The pilot's action may have been well early with respect to collision so non-predictive does not necessarily mean late). Alerts that are not associated with any such observed escape behavior may be termed "false" alerts. No escape maneuvers were observed without an alert, i.e., no missed alarms.

It is clear, that an automatic system such as ATS would aim at maximizing the ratio of the true alerts to false alerts. It should also be recognized that the absolute rate of alarms would be a separate engineering consideration. Even at a fairly high true alarm to false alarm ratio, if the total alarms per hour are too high, it may not be desirable to use that particular logic. In this section a detailed study of this phenomenon is made.

By assigning specific threshold values to the basic logical schemes (A, B, C, G) described in Section 4.1, several specific candidate logics can be considered. Table 4-2 describes ten different threat detection logics (labeled LP1-LP10) created by selecting specific parameters for the previously studied logic schemes. The total number of alarms issued and their composition into true, predictive and false alarms are described in each case. Thus, a basic tau-logic LP4 which incorporates a 20 second tau threshold, declares a total of 22 conflicts, only six of which are true. This implies almost three false alarms for every true alarm. By introducing a miss-distance criterion as in LP8, for the same tau-threshold, a total of 12 conflicts are declared, four of these being true. Here we have two false alarms for each true alarm. For LP7, which uses a 15 second tau-threshold, we get more true alarms than false alarms. We see generally that increasing threshold values greatly increases false alarms.

An automatic conflict alert system aims at giving a warning to the pilot in sufficient time to avoid collision. The concept of the predictive alert attempts to describe those alerts which were given prior to the pilot's observed maneuver. We see that for all logics, about 40% to 50% of all true alerts are predictive.

4.3 A Regional Analysis

We expect that for each logic, certain regions of the airspace contribute more false alarms than others. The entry-downwind region is "sloppier", due to aircraft entering at different points on downwind and inherently exhibits higher closing rates. The final approach region, in contrast, generally contains more structure due to tighter in-trail geometries. We may expect each logic to function differently in these regions. We have already seen that we expect different values for the average straight line flight time in different parts of the pattern. Thus, different parts on the pattern impose different upper limits on lead time values. A ground-based system may be able to identify where in the pattern area an aircraft is, and thus be able to use those various differences to optimize the total

TABLE 4-2
EFFECTIVENESS OF LOGICS FOR DETECTING TRUE(2) CONFLICTS IN MANASSAS-II

LOGIC SCHEME		LP #	LOGIC(1)	TRUE(2) PILOT ALREADY MANEUVERING CLEAR	TRUE(2) PREDICTIVE(2) (1 TO 3 SCANS AHEAD)	TRUE(2) TOTAL TRUE	FALSE	TOTAL # OF CONFLICTS DECLARED IN 45 MIN.
ACAS TYPE	A	LP 1	$R \leq 0.2$	2	2	4	3	7
		LP 2	$R \leq 0.3$	3	3	6	21	27
	B	LP 3	$\tau \leq 15/R \leq 0.2$	3	2	5	7	12
		LP 4	$\tau \leq 20/R \leq 0.2$	3	3	6	16	22
	C	LP 5	$\tau \leq 15$ & $R \leq 0.4/R \leq 0.2$	3	2	5	7	12
		LP 6	$\tau \leq 20$ & $R \leq 0.4/R \leq 0.2$	3	3	6	13	19
GROUND BASED TYPE	G	LP 7	$\tau \leq 15$ & $MD \leq 0.2/R \leq 0.2$	2	2	4	3	7
		LP 8	$\tau \leq 20$ & $MD \leq 0.2/R \leq 0.2$	2	2	4	8	12
		LP 9	$\tau \leq 25$ & $MD \leq 0.2/R \leq 0.2$	1	1	2	11	13
		LP 10	$\tau \leq 25$ & $MD \leq 0.3/R \leq 0.2$	3	2	5	20	25

NOTES:

1. Vertical threshold = 500 feet for all logics. Range threshold is in nmi.
2. See Glossary
3. All counts are for the 45 minute duration of the model.
4. All conflicts detected by LP 7 are also detected by LP1, although *sometimes a little later.*
5. All conflicts detected by LP 5 are also detected by LP 3.
6. LP 8 detects some different conflicts from LP 5 and LP 3. In LP9, an alert was given earlier than the 12 second cutoff to be considered.

number of alarms it issues. In this section we study the behavior of each logic in different regions of the airspace. The system variables considered are the predictive and total alarms.

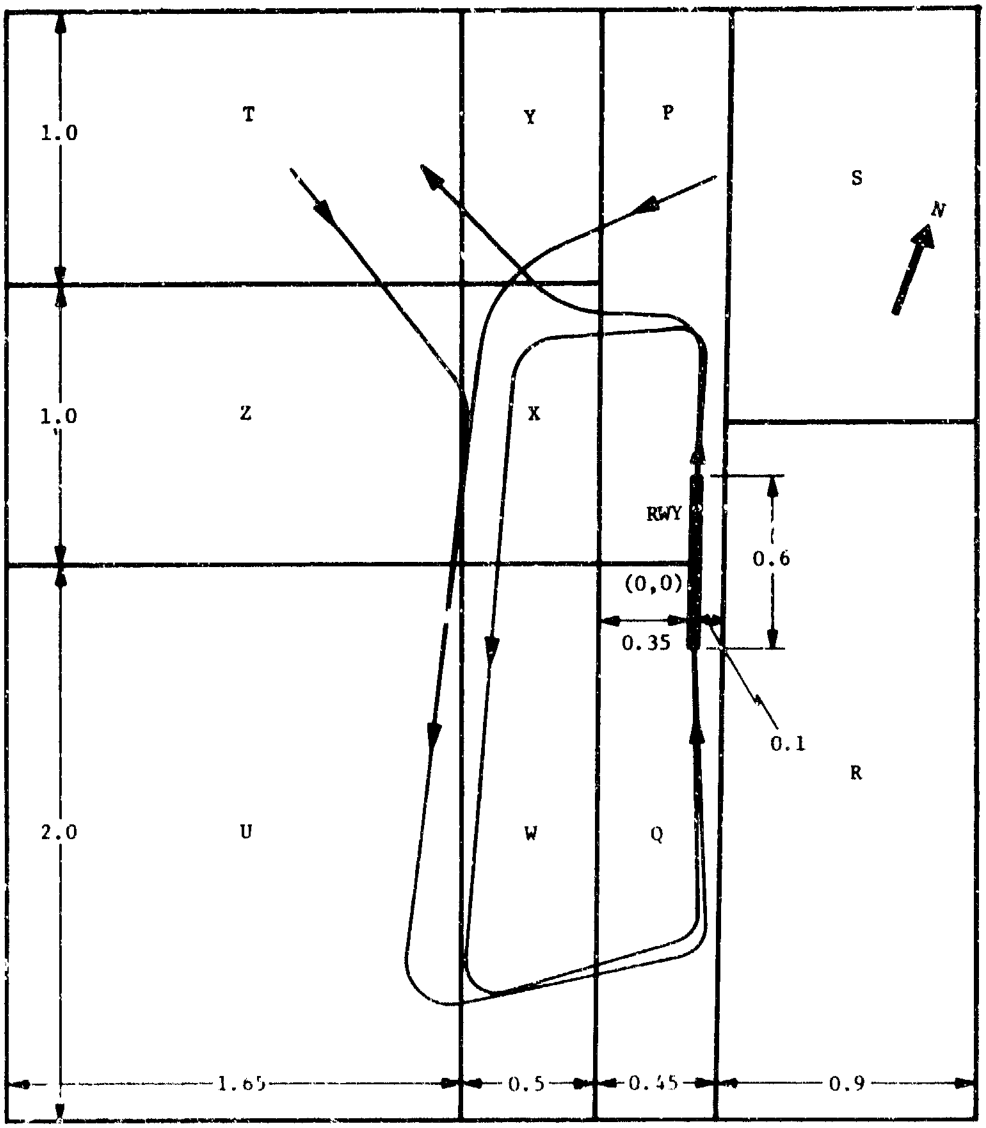
Figure 4-6 shows the region map used for this study. It contains 10 rectangular zones. The average pattern for MANASSAS-II is shown superimposed on it. For each logic used in Table 4-1, we now provide "aircraft alert position counts" of aircraft detected to be in conflict. This is done as follows.

Suppose a conflict involving aircraft A and aircraft B has been detected by Logic LP of Table 4-2. Suppose A is in zone Zi and B in Zj at the first scan that the conflict is detected. The "aircraft alert position count" for these two zones is updated by one each. In addition, if the detection occurred from 1 to 3 scans before either A or B was observed to make an escape maneuver, then the "predictive alert count" in each zone is also updated by one. The total counts for the entire model (i.e., for all aircraft pairs in MANASSAS-II) are provided in the maps of Figure 4-7, one map for each logic. The pair of numbers (n,m) in each zone refer to its total "aircraft alert positions count" and the total "predictive alert positions count" respectively. The number of aircraft positions are always twice the number of conflicts.

We see that Logic LP2 is extremely efficient in the entry region Z whereas it gives unnecessary alarms everywhere else. Logic LP7, in contrast, does not do quite as well in entry region Z, but is able to predict some other conflicts in the downwind-entry region X and significantly reduces unnecessary alarms everywhere else. Suppose we use logic LP2 (i.e., $R \leq 0.3$) in the entry zones T and Z, and use logic LP7 (i.e., $T \leq 15$ and $MD \leq 0.2 \mid R \leq 0.2$) everywhere else. Figure 4-8 shows a simplified region map depicting this. A detailed accounting for each conflict shows that with such a combination logic, we would declare a total of 8 conflicts, 4 of which would be predictive. This is a significant improvement in "predictive" alarms over anything seen in Table 4-2.

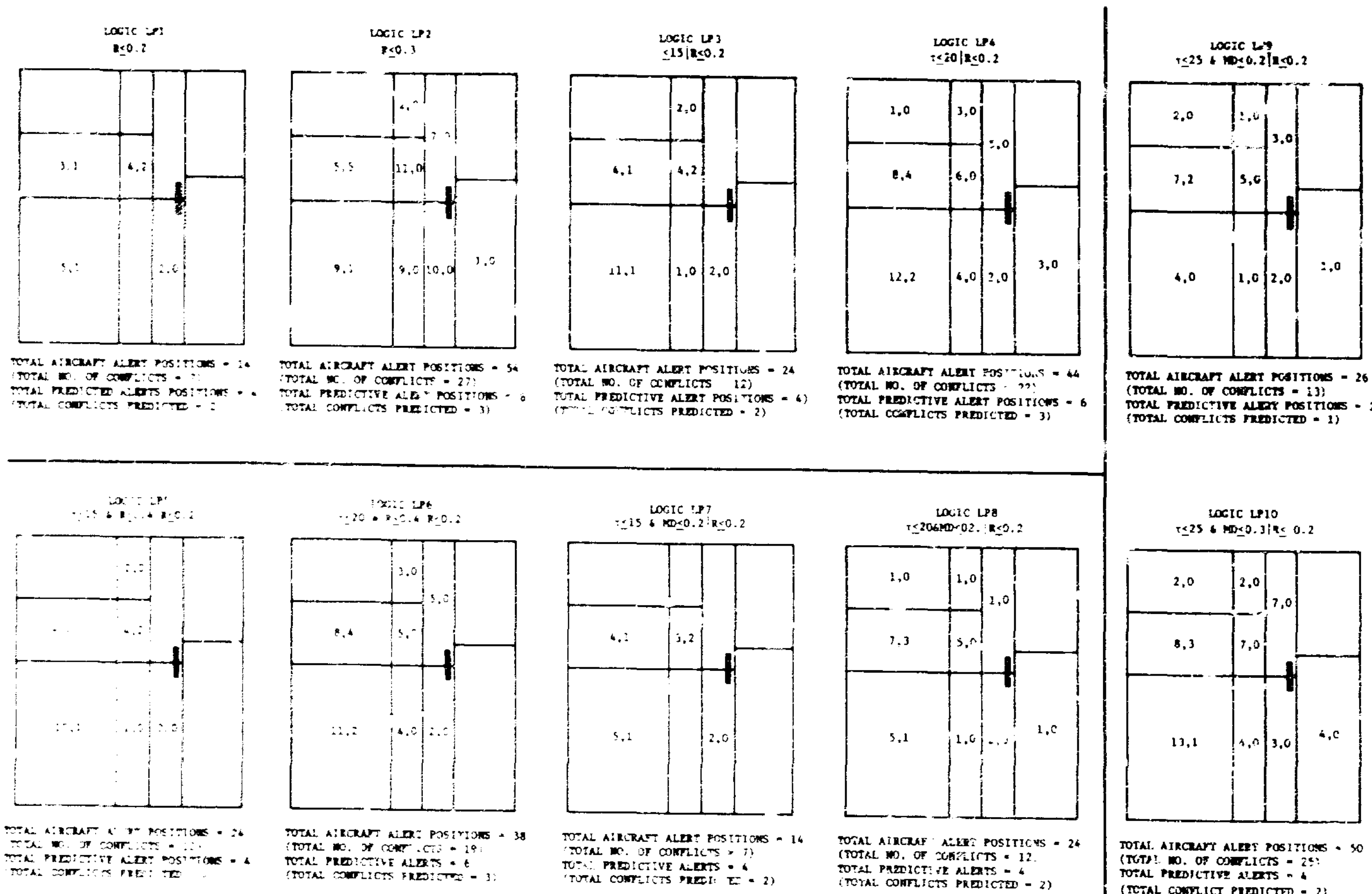
Other logic combinations are possible. The one described above provides the best ratio of total alerts to predictive alerts, while also giving a very small number of total alerts.

We conclude that the use of a region-dependent logic in the traffic pattern can provide a definite improvement over using any one logic over the entire pattern area. This approach should be explored in designing the threat detection logic of an Automated Terminal System.



NOTES: ALL DIMENSIONS IN N.MI.
MANASSAS-II PATTERN IS SHOWN SUPERIMPOSED.

FIGURE 4-6
A REGION MAP FOR MANASSAS TERMINAL AREA

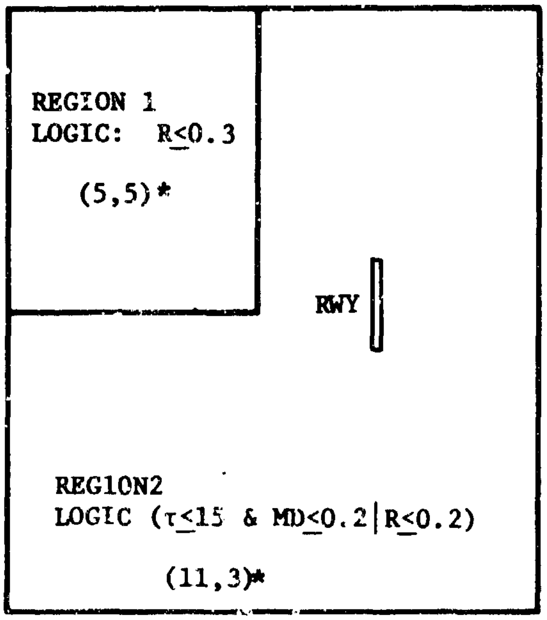


LEGEND: PAIRED NUMBERS (A,B) IN EACH REGION DENOTE:

A = TOTAL NO. OF AIRCRAFT POSITIONS FOR CONFLICTS DETECTED. ONLY ONE POSITION PER AIRCRAFT, THE POSITION WHEN CONFLICT FIRST DETECTED.

B = TOTAL NO. OF AIRCRAFT POSITIONS WHEN CONFLICT PREDICTED 1 TO 3 SCANS AHEAD OF OBSERVED MANEUVER

FIGURE 4-7
REGIONAL ANALYSIS OF THE EFFECTIVENESS OF LOGICS



REGION 1 = REGIONS T&Z OF FIGURE 4-6
REGION 2 = ALL OTHER REGIONS OF FIGURE 4-6
TOTAL NO. OF CONFLICTS DECLARED = 16/2 = 8
TOTAL NO. OF CONFLICTS PREDICTED WITHIN 4 TO 12
SECONDS OF OBSERVED MANEUVER = 8/2 = 4

* SEE LEGEND IN FIGURE 4-7 FOR
EXPLANATION OF PAIRED NUMBERS.

FIGURE 4-8
A COMBINATION LOGIC MAP FOR MANASSAS-II

5. SUMMARY

This section will note some of the implications of the data presented above for the Automated Terminal Services concept and also briefly discuss use of an ACAS system in the traffic pattern.

The first general observation is that even with no present regulatory requirements beyond the general left hand traffic rule, traffic usually follows the standard traffic pattern. As many as 150 hourly operations have been observed at Manassas Airport and characteristics of the traffic pattern change considerably with how busy it is. At low traffic densities, greater individual variation and more unorderly behavior is seen. At higher traffic densities traffic tends to follow the standard pattern more closely and once in pattern, tends to order itself more. It appears that using the traffic pattern as the basic organizing tool for an automated system will be effective. The natural orderliness of the traffic also indicates that practical sequencing aids for the pilot can be developed.

The design of a threat detection logic for ATS will be influenced by some basic points:

1. In the uncontrolled traffic pattern during high density operations, there is a significant incidence of pilots electing to maneuver because of the proximity of other traffic. If the ATS system generates a warning for these cases, the design goal can not be zero alerts during normal operations.

2. Traffic proximity is such that even modest τ and range criteria yield relatively frequent alerts.

3. The logic should attempt to alarm only on the irreducible "true" conflicts. Factors in designing an acceptable logic include:

   a. use of a miss distance criterion.

   b. exploitation of the varying traffic spacing and intent in the various regions of the traffic pattern.

   c. thresholds might be set tighter during high density operations (since aircraft are observed to operate with more order) and expanded during periods of low traffic.

These will be pursued in developing an effective ATS logic.

Finally, some preliminary estimates of the behavior of an ACAS system in the traffic pattern can be made as a result of this work. First, the 30 second warning times that have been considered for ACAS designs become marginally acceptable in the pattern. Even a CAS logic with protection volumes defined by tau $\leq$ 15 seconds and immediate range $\leq$ 0.2 nmi yields an alarm rate of about 1 every 5 minutes. About 15% of these alarms are true predictive alerts.

Second, an alert without directional proximity warning information (PWI) may be almost ineffective in this environment due to the high probability of multiple targets in the immediate vicinity and the low tau-values we are considering. These two factors together would make pilot's sighting the particular threat aircraft quite difficult. This is especially true in the downwind-entry region where traffic is more scattered and closure rates are higher.

An ACAS system even with low τ thresholds would provide some protection in low closure rate areas such as final approach. Historical data [2] indicates that about 2/3 of all midair collisions occur at low convergence angles and this system would be expected to be useful in those cases. It should be noted however, that vertical commands are not very usable in the pattern. Descend commands can not be issued due to terrain proximity and climb-commands are undersirable because they disrupt the pattern. It would therefore appear that an ACAS system in the traffic pattern must at most be used to give a simple, short look-ahead advisory in case of a threat and leave the avoidance maneuver to the pilot.

APPENDIX A

DATA COLLECTION AND REDUCTION

This appendix provides full details of the model building activity. An overview has been given in section 2.3. Here, the elements of the process are elaborated.

The raw data is time of event data that can be utilized to identify specific events in the flight of each aircraft. In addition, a special technique is used to compute speed and position of downwind aircraft. Section A.1 describes this technique, in theory. Section A.2 provides the full experimental details of gathering all required information. Section A.3 describes the process used for reducing the raw data.

A.1 Speed and Position Measurement: Theory

We describe here the technique for computing speed and position of an aircraft in straight flight.

In Figure A-1, let PQR be the path of an aircraft AC moving at ground speed V. We set up two observers A & B and three fixed lines of sight, L1, L2 and L3 as shown. L1 and L3 are parallel and both are perpendicular to AB. L2 is at an angle θ to L1. Let T1, T2 and T3 be the absolute times of crossing of AC at these three lines of sight. Thus T1 < T2 and T1 < T3. Then,

$$\frac{PQ}{PR} = \frac{T3-T1}{T2-T1}$$

Let RQ1P1 be a line parallel to AB through R. Then,

$$\frac{PQ}{PR} = \frac{P1Q1}{P1R}$$

$$\frac{P1Q1}{P1R} = \frac{T3-T1}{T2-T1}$$

$$P1R = D * \frac{T2-T1}{T3-T1} \qquad (1)$$

and

$$P1A = P1R * \cot\theta$$

$$= D * \frac{T2-T1}{T3-T1} \cdot \cot\theta$$

D, T1, T2, T3 and θ are known. Hence P1R and P1A are known. Thus the x and y offsets of the aircraft at time T2 are known with respect to the point A and the line AB.

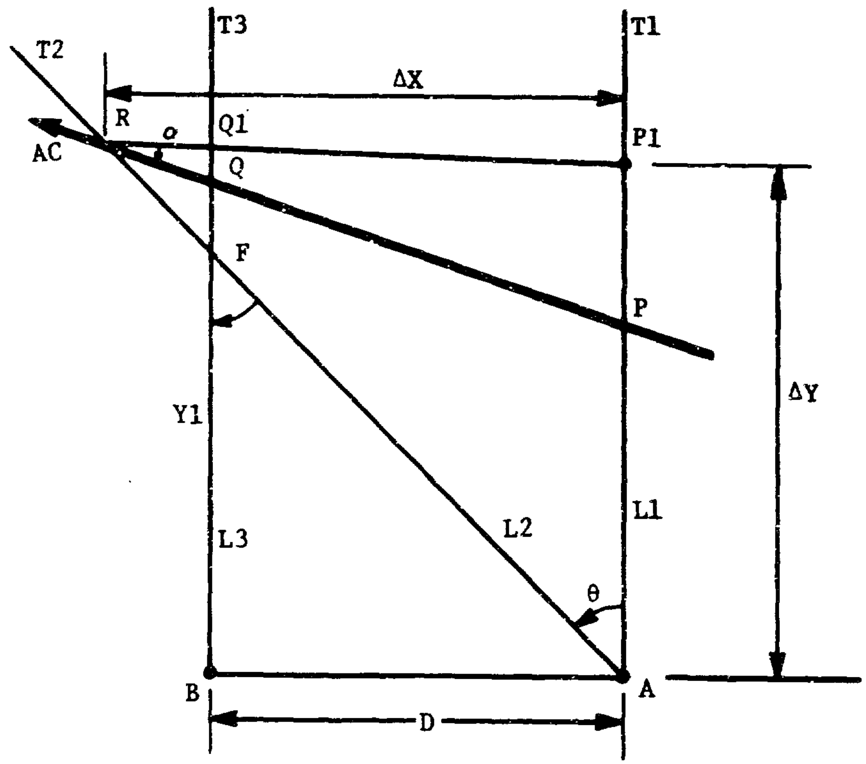


FIGURE A-1
SPEED AND POSITION MEASUREMENT

Further, let VX be the component of speed along AB. Then

$$VX = \frac{P1Q1}{T3-T1} = \frac{D}{T3-T1}$$

and VX is thus known.

$$V = \frac{VX}{\cos\alpha}$$

and hence

$$\left(\frac{V-VX}{VX}\right) = \sec\alpha - 1$$

If α is $\leq 16^{\circ}$, V is within 5% of VX

If α is $\leq 23^{\circ}$, V is within 10% of VX

The next section includes description of the experimental procedure used to exploit these relationships to compute point R and speed.

A.2 Experimental Procedure

The fully implemented procedure, used only in the high density case, involves 6 observers. 4 of these are used for gathering time of profile events (turn times, etc.) and 2 for the speed and position measurement on downwind. We describe the following three aspects in turn:

- Technique of time measurements
- Division of responsibility amongst observers
- Speed and downwind offset measurements.

Time was recorded by using portable (battery operated) cassette recorders that ran continuously. An observer simply recorded a continuous verbal commentary of the events he perceived. (Example: the red and white high wing is turning to crosswind <u>now</u>.) Since this was recorded in real time on the cassette tapes, the tape was simply played back later to retrieve the time information. In order to minimize the small nonlinear variations in recording speed and the consequent discrepancies between recording and playback times, frequent time hacks off wrist watches with sweep second hands were included in the commentary. (Example: At the hack, it will be 1:32 and 50 seconds. HACK.) All watches were synchronized before starting. Cassettes run for 45 minutes on each side. Hence the 45 minute model!

Four observers are used to record time-of-event information about the traffic pattern traffic. They record information of the type described earlier in Table 2-2. Due to the dimensions of the pattern (approximately 1 mile out) no one observer is able to observe the entire pattern with clarity. Observers therefore take responsibility to note events in a certain part of the pattern, as shown in Figure A-2. Redundancy is provided between observers, for the sake of reliability and correlation. Finally, for purposes of correlation, each observer notes the physical appearance (color, wing-type) of each aircraft and gives the last three alphanumerics of the tail number whenever possible. In cluster situations, context is used for description. Binoculars are provided for help in identification. The only equipment these observers need, then, are tape recorders, wrist watches and binoculars.

Two observers corresponding to positions A and B in Figure A-1 are needed for speed and position measurement. The measurements are made for aircraft on downwind as they approach threshold, thus getting ready to turn base. The fixed, known lines of sight (see Figure A-1) required by the method are provided by the use of surveying transits, one for each line of sight. Figure A-3 shows the positions of the observers, A & B, and the set up of their transits T1, T2 and T3. <u>A</u> monitors T1, T2 and <u>B</u> monitors T3. Each transit-telescope is fixed in azimuth, but free to move in the vertical plane. Thus, each provides a fixed vertical plane, corresponding to L1, L2 and L3 in Figure A-1.

A and B have a tape recorder each. On these are recorded transit crossings of aircraft, again in real time: i.e., the tape recorders are continuously operated, to be played back later for extracting the time information. (Example: "Low wing aircraft approaching Transit #1 - HACK". The HACK corresponds to the aircraft crossing the vertical line in the telescope.) Time of transit-crossings can, in principle, be obtained more accurately than the accuracies of playback and correlation allow. These observers are therefore each provided with a radio receiver receiving a continuous time signal from WWV (a beep each second and time of day each minute). This is being recorded on their tapes in the background. In addition they are equipped with a pair of walkie-talkies. <u>A</u> transmits all his information on transit crossings to <u>B</u>. <u>B</u> thus has a record of all three transit times on his tape, improving accuracy of difference measurements and greatly helping correlation of aircraft in hectic traffic conditions.

<u>A</u> & <u>B</u>'s positions are known accurately with respect to the runway. Calibrations are made at the conclusion of experiment for the actual angles at which the transits were aimed. For calibration of speed

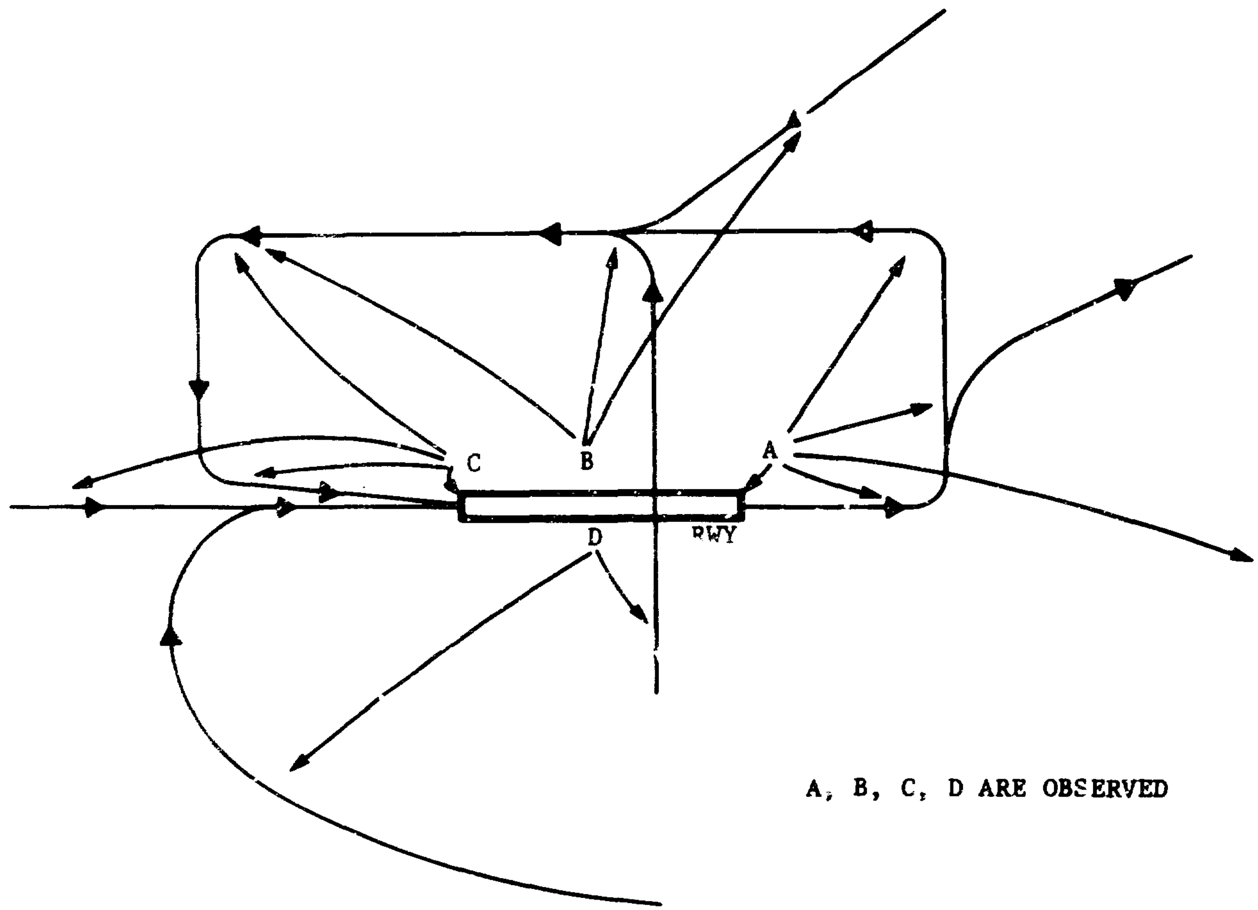


FIGURE A-2
RESPONSIBILITIES OF OBSERVERS

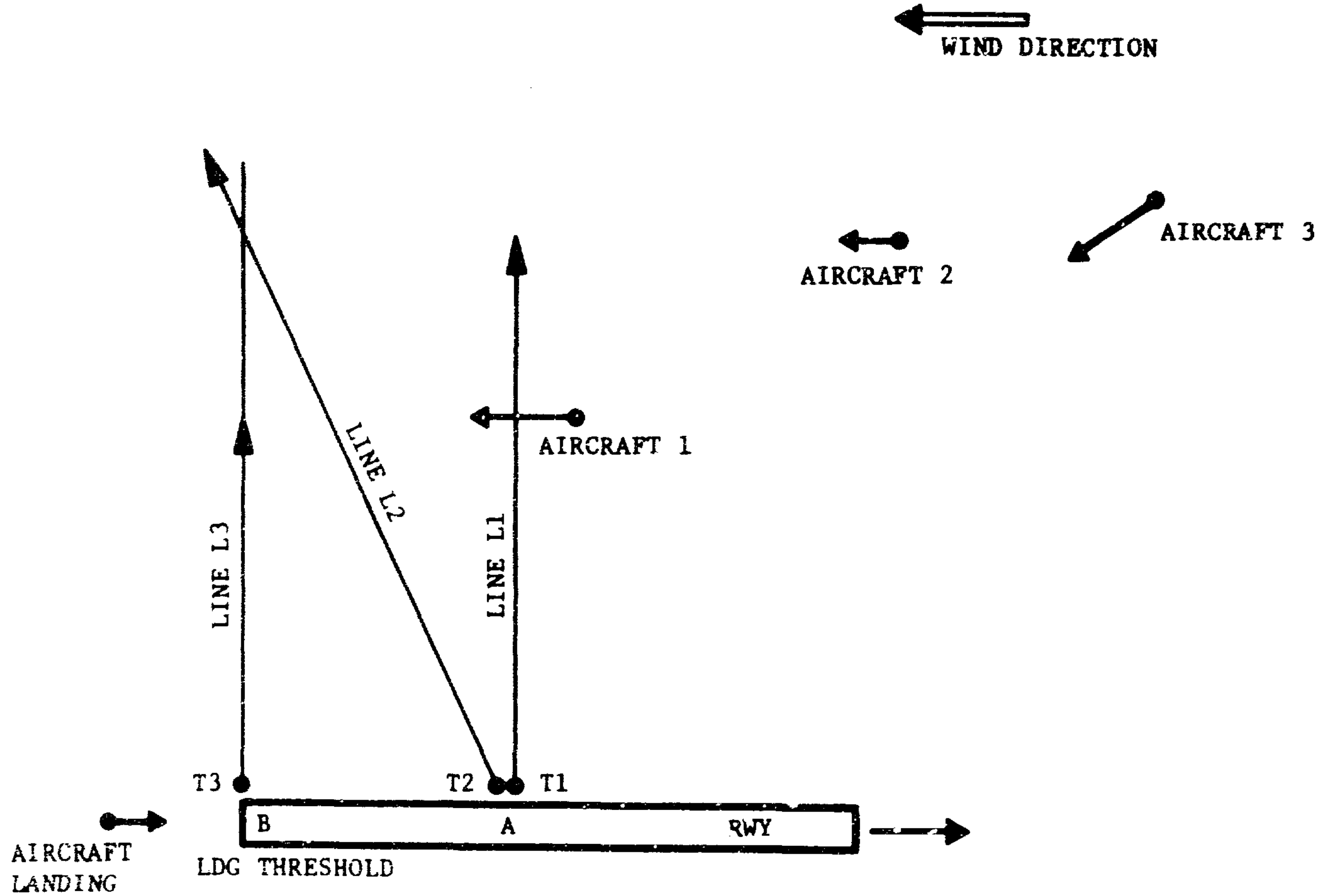


FIGURE A-3
EXPERIMENTAL SET-UP FOR SPEED AND POSITION MEASUREMENT

and distance measurements, two test flights by a test pilot are made, the pilot flying at known airspeeds and over known landmarks.

A.3 The Data Reduction

Data on the voice tape obtained from each observer is first transcribed into raw data about events in particular geographical sections of the traffic assigned to each observer. This data is correlated to yield raw data on all events of each track observed in the area. A "track"* is defined as the path of an aircraft from initial acquisition up to the point of crossing threshold to land (for circulating or arriving aircraft) or up to the point at which last seen (for aircraft departing from the runway). Thus, an aircraft arriving from outside the airport, doing 4 circulating patterns (by touch and go's or otherwise) and then leaving the airport, contributes 1 + 4 + 1 = 6 tracks in this model. Each aircraft never landing at the airport (an "over flight") yields 1 track. Each track is represented by a series of concatenations of straight and curved flight paths called profile. All speed changes are assumed to take place in the straight sections. All turn sections are assumed to be at constant speed and constant bank angles. Since a wind of at least 10 knots was present for both experiments, the turns were not circular in reality. The approximation to represent the flight during a turn is shown in Figure A-4. AB is the acutal path of the aircraft. Time in AB = TTURN. V1, V2 are ground speeds of the aircraft. WD is the wind speed, assumed to be along V2. AB is approximated by one circular section AC of duration TTURN at speed V1 and a straight section of duration DT with acceleration $(\frac{V2-V1}{DT})$ where $DT = (WD/(V + \frac{1}{2} WD)).TTURN$. The time DT is taken up from the straight section that follows turn AB. This scheme yields the exact coordinate and velocity values at A and B after approximation. The errors introduced are reflected in the time DT and the values during turn. For the environment in question, these are acceptable.

The basic scheme of speed changes assumed in the pattern is shown in Figure A-5. This was tailored as necessary if other factors (fit or minimum speeds) required changes in a particular track.

As for turn angles, rectangular turns are assumed to start with, unless otherwise known as in cases of entry on downwind. Projections through each section are made to see discrepancies in known positions

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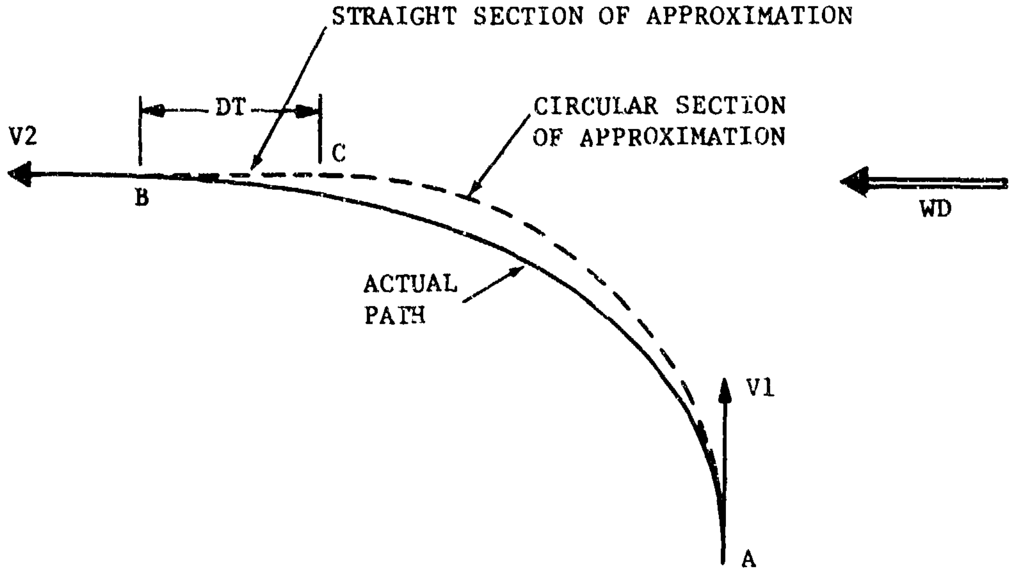
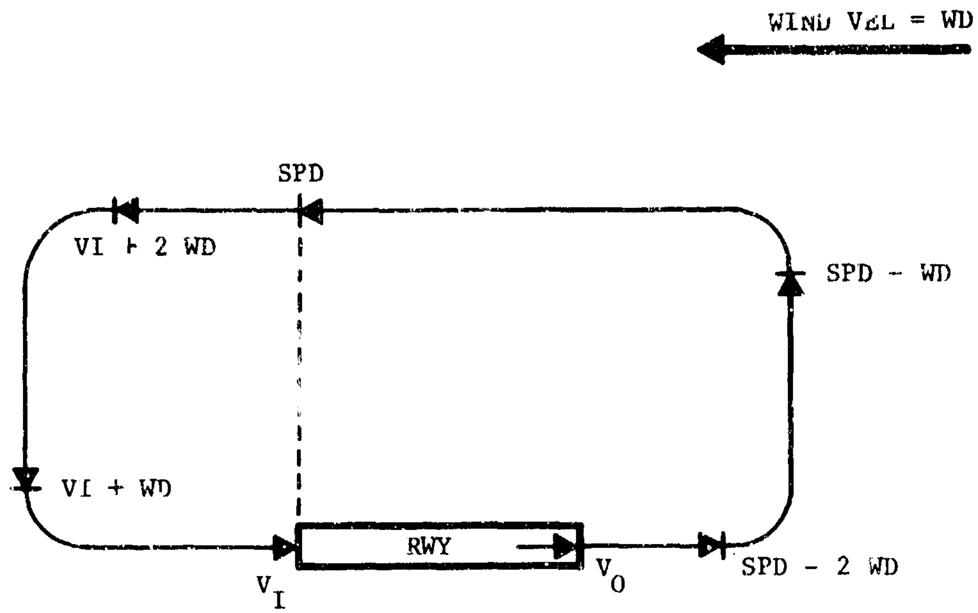
* See Glossary



V1, V2 ARE GROUND SPEEDS
WD IS WIND SPEED
V2 = V1 + WD
TTURN = ACTUAL TIME OF TURN
DT = (WD/V + 1/2 WD) · TTURN

FIGURE A-4
APPROXIMATION OF A TURN IN PRESENCE OF WIND



SPD = MEASURED GROUND SPEED OF AIRCRAFT ON DOWNWIND

WD = KNOWN WIND SPEED

V_O = ASSUMED OUTBOUND GROUND SPEED $(80 \pm$ [illegible]$) - WD$

V_I = ASSUMED INBOUND GROUND SPEED $(70 \pm 10) - WD$

FIGURE A-5
ASSUMED PROFILE FOR GROUND SPEED CHANGES IN THE PATTERN

(downwind at threshold, threshold at landing). Angles are adjusted until an exact fit to known positions is obtained. Note that a fit implies specific positions at specific time. Any known information from observers' descriptions of the flight is incorporated to make this fit as realistic as possible.

When all tracks are fitted, they contain exact flight-plan type data (in their "profiles"). A reasonable profile for altitude changes is assumed for each aircraft, based on qualitative observations of observers. Each such track, represented by one horizontal and one vertical profile, is now translated into a 4-second scan data set. All these data points are then sorted on absolute time to yield a 4-second scan picture of the entire traffic.

The resulting "model" is tested for unusually close encounters. The criterion used to find these "unusually close" encounters is as follows:

$$(\text{ALTSEP} < 300 \text{ FEET}) \; \& \; \left(\frac{\text{RANGE}}{\text{RANGE RATE}} < 12 \text{ SEC} \,\middle|\, \text{RANGE} < 800 \text{ FEET}\right).$$

where ALTSEP = Vertical Separation; RANGE = Relative Horizontal Range.

For aircraft pairs violating these criteria, individual profiles are studied and altered as necessary to eliminate the construction induced violations. Such a cleanup was only necessary for MANASSAS-II. Out of its 79 total tracks, 10 were found to violate these criteria in the first cut of the model. They required minor alterations in turn angles or speeds to yield the cleaned data set now named MANASSAS-II.

APPENDIX B

ACCURACY OF THE MODELS

This section contains estimates of how closely the models approximate the traffic actually observed.

B.1 Overall Accuracy

Factors that affect the overall accuracy of the models can be identified as follows:

- Accuracy of time-of-event observations
- Accuracy of the turn approximation
- Accuracy of speed and position measurements on downwind
- Accuracy of assumed speed changes
- Accuracy of assumed headings.

We now discuss these in turn.

Times of events (such as crossing threshold) are observable at about 2 sec (1σ value) accuracy. At 70 knots, the error at crossing threshold is 220 ft (1σ value).

The time-inaccuracy introduced in the turn approximation for a 10 knot wind for a 90 knot aircraft turning for 10 seconds is 1 sec. Since there is a 2 sec error in noting the time of turn event itself, the net error is $\sqrt{5} = 2.3$ sec. At 150 ft/sec, this implies a position error of 350 feet.

Section B.2 provides a detailed analysis of the accuracy of speed and position measurements on downwind. Speed errors (gaussian) of 4 knots (1σ) and position errors of 220 ft (1σ) are estimated for these measurements.

When downwind speed is known (as in MANASSAS-II) speeds everywhere else in the pattern are estimated to be accurate to within 10 knots (1σ value). In MANASSAS-I, this same value is estimated at 20 knots.

The largest inaccuracies in headings occur for entering aircraft before they cross threshold on downwind and for departing aircraft after then turn off crosswind. (And of course, for over-flights).

In the remaining sections of the pattern, inaccuracies in heading are a function of the overall "fit" and hence depend upon the inaccuracies mentioned above.

B.2 Accuracy Estimate of Downwind Speed and Position Measurements

Let Y be the downwind offset and VX the X component of speed on downwind, at threshold. Referring to Section A and Figure A-1, we have:

$$Y = \frac{T2-T1}{T3-T1} \cdot D \cdot \cot\theta$$

$$VX = \frac{D}{T3-T1}$$

where D = distance between transits T1 and T3
θ = angle between transits T1 and T2.

For MANASSAS-II, D = 1212 feet; θ = 20°, nominally

Hence,

$$Y = \frac{(T2-T1)}{(T3-T1)} \cdot 1212 \cdot \cot\theta \qquad (1)$$

$$VX = \frac{1212}{T3-T1} \qquad (2)$$

Calibrations made for the lines of sight and by test flights require some modification of these formulae. The lines of sight were not at exactly 90° and 70° as required. Instead L1, L2 and L3 were at 90.25°, 69.8° and 88.34° respectively. The slight deviations can be accounted for by a division factor of 1.0246. The calibration flight provided speed and distance that would be consistent with these formulae, if the measured speed was multiplied by 0.9275. (This may be seen as a fixed bias of 7%, affecting all measurements in the same direction.) Thus, both equations (1) and (2) need to be multiplied by $\frac{0.9275}{1.0246}$, yielding:

$$Y = \frac{T2-T1}{T3-T1} \cdot 2987 \text{ feet}$$

$$VX = \frac{1097}{T3-T1} \text{ feet per second}$$

Use of radio-synchronized time signals makes it possible to measure time-differences (T3-T1) and T2-T1) to within 0.15 seconds. (T3-T1) and (T2-T1) are both of the order of 10 seconds. Errors in Y and VX are therefore given by

$$\varepsilon_Y = 3\% \text{ of } Y$$

$$\varepsilon_{VX} = 1.5\% \text{ of } VX$$

For Y = 4800' and VX = 160 ft/sec, this yields

$$\varepsilon_Y = 150 \text{ feet}$$
$$\varepsilon_{VX} = 2.5 \text{ feet/sec} \qquad \text{(I)}$$

The uncertainty in the direction of the track independently affects the accuracy to which Y and speed are known. In Figure A-1, PQR is the true track. All the above estimates, however, have been made assuming P_1Q_1R as the true track. Thus QQ_1 is the error in Y resulting from the track angle α. Let $\Delta Y = QQ_1$. Then

$$\Delta Y = (Y \tan\theta - D) * \tan\alpha$$

and if V is the true speed, then

$$\Delta V = (V - VX) = VX * (\sec\alpha - 1)$$

At V = 150 ft/sec, Y = 4800', D = 1200', θ = 20° and α = 15°,

$$\Delta Y = 150 \text{ feet}$$
$$\text{and} \quad \Delta V = 6 \text{ feet/sec.} \qquad \text{(II)}$$

If α = 15° be a 1σ value, then equations (II) simply reflect the 1σ errors caused by this uncertainty in aircraft track heading.

The values given by equations (I) and (II) can be root mean squared to yield the 1σ values of errors in downwind offset Y and speed V.

$$\sigma_Y = \sqrt{150^2 + 150^2} = 220 \text{ feet}$$

$$\sigma_V = \sqrt{6^2 + 2.5^2} = 6.5 \text{ feet/sec} = 4 \text{ knots}$$

Note that there exists a separate 7% fixed bias error, affecting all Y and V values in the same direction.

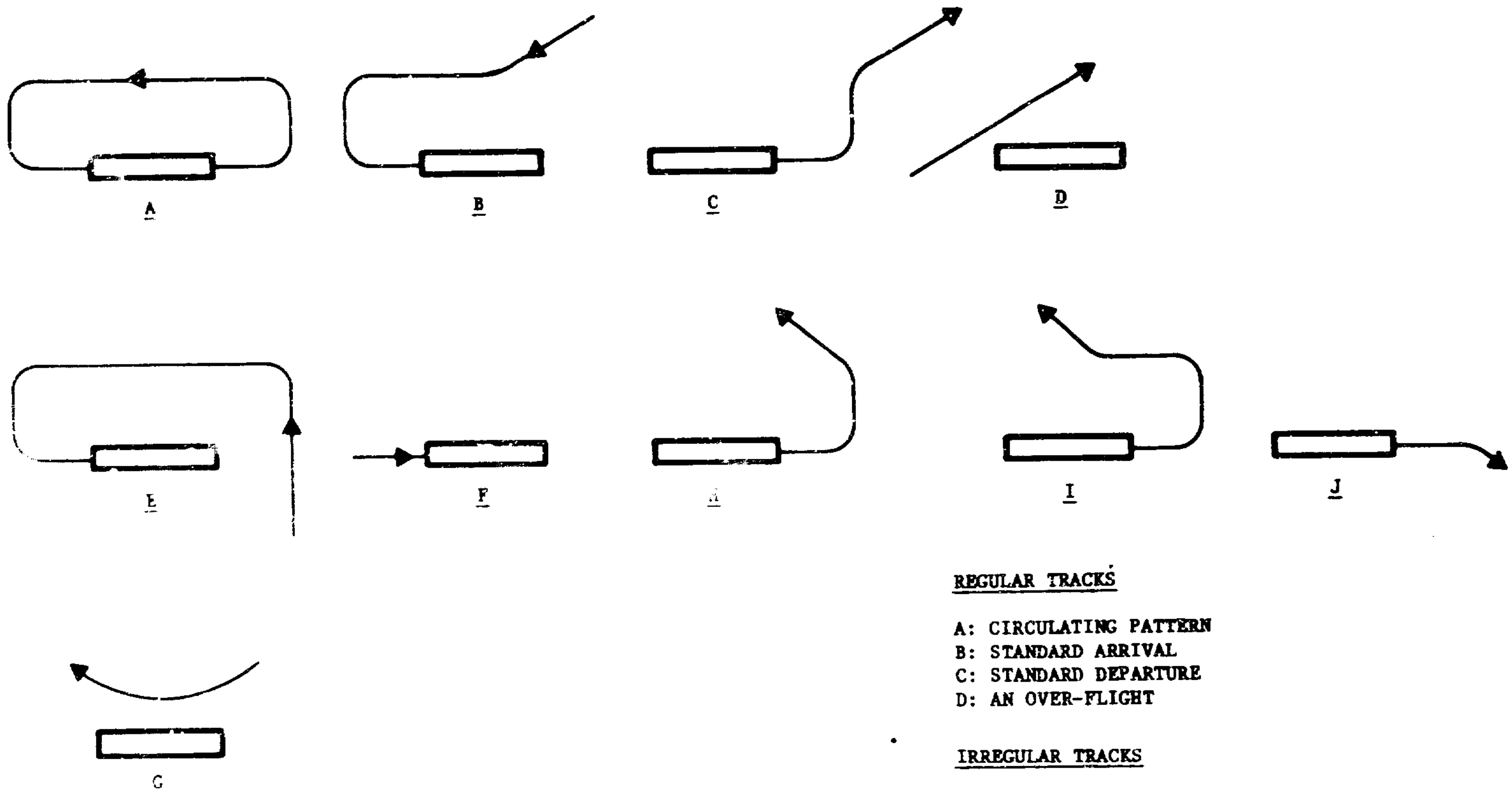
APPENDIX C

GLOSSARY AND EXPLANATION OF TERMS

Airport Operation:	A landing, a take off or an over flight. (A touch and go thus contributes two operations.)
Circulating Pattern:	A flight such that an aircraft takes off and lands at the runway without ever leaving the airspace. See Diagram A in Figure C-1.
Continuous Flight:	A continuous flight ends only when an aircraft leaves the airspace or lands and either joins the departure que or leaves for good. Thus, an aircraft executing five circulating patterns by touch and go's, joining the departure que and making another circulating pattern contributes only two continuous flights.
Track:	A track is the smallest logical flight an aircraft may have in the airspace. A track ends everytime an aircraft crosses the threshold to land or leaves the airspace. A track begins when an aircraft enters the airspace or when it takes off from runway. Figure C-1 shows types of tracks that are common. An aircraft coming from afar, doing a touch and go and one pattern and then leaving the runway thus contributes three tracks but only one continuous flight. An aircraft doing ten patterns all by touch and go's, contributes ten tracks but only one continuous flight. A track contributes one operation except for a circulating pattern, where it contributes two operations.
Traffic Pattern Section	See Figure C-2.

Abbreviations:

CAS	Collision Avoidance System



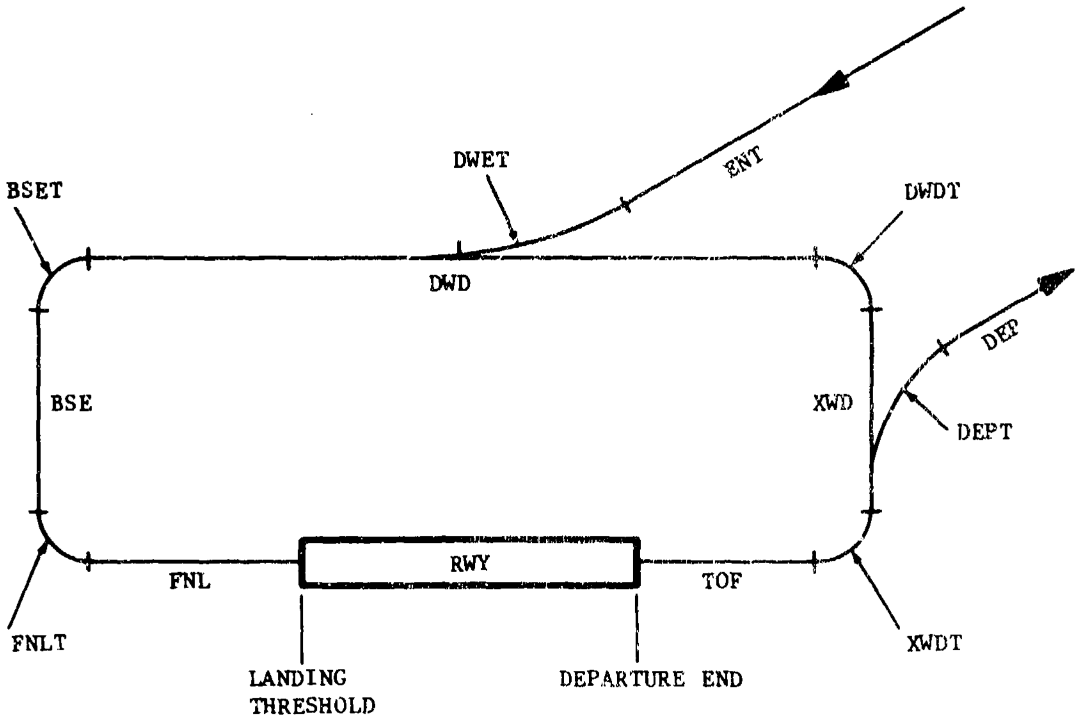
<u>REGULAR TRACKS</u>

A: CIRCULATING PATTERN
B: STANDARD ARRIVAL
C: STANDARD DEPARTURE
D: AN OVER-FLIGHT

<u>IRREGULAR TRACKS</u>

E: CROSSWIND ENTRY
F: STRAIGHT-IN ARRIVAL
G: ABORTION ON ENTRY
H: DEPARTURE BY LEFT TURN ON CROSSWIND
I: DEPARTURE BY ABORTION ON DOWNWIND
J: DEPARTURE BY RIGHT TURN ON TAKEOFF

FIGURE C-1
TYPES OF TRACKS



TOF	-	TAKEOFF LEG	XWDT	-	TURN TO CROSSWIND
XWD	-	CROSSWIND LEG	DEPT	-	TURN TO DEPARTURE LEG
DEP	-	DEPARTURE LEG	DWET	-	TURN TO DOWNWIND FROM ENTRY LEG
ENT	-	ENTRY LEG	DWDT	-	TURN TO DOWNWIND FROM XWD
DWD	-	DOWNWIND LEG	BSET	-	TURN TO BASE
BSE	-	BASE LEG	FNLT	-	TURN TO FINAL
FNL	-	FINAL LEG			

FIGURE C-2
ABBREVIATIONS FOR PATTERN SECTIONS

Regular Track:	A track that conforms to the standard left hand pattern.
Irregular Track:	A track that does not conform to the standard left hand pattern.
True Detection:	A conflict detection where the detection first occurs in immediate temporal vicinity of the time when an aircraft involved in this conflict is actually observed making an escape maneuver.
Predictive Detection:	If a detection first occurs 1 to 3 scans (i.e., 4 to 12 seconds) ahead of the time when an aircraft is actually observed maneuvering, it is called a Predictive Detection.
False Alarm:	An alarm issued when the conflict is not "true" by the above definition.

APPENDIX D

DATA FORMATS

The data for each model exists on tapes. MANASSAS-I data is on Tape #293 and MANASSAS-II on Tape #008 in the MITRE/Washington Computing Center. The tapes are unlabelled, CMS compatible data sets written under the VM operating system.

The data set exists in the form of a series of 4 sec. scan pictures of the airspace, sorted on time, one record per aircraft. Each record is 40 bytes long and is written in the following PL/I structure:

```
1 AC  STATIC
  2   TIME BINARY FIXED (31),
  2   ID CHAR (7),
  2   FLG BIT (8),
  2   XAC BIN FLOAT,
  2   YAC BIN FLOAT,
  2   ZAC BIN FLOAT,
  2   GSPD BIN FLOAT,
  2   XD BIN FLOAT,
  2   YD BIN FLOAT,
  2   ZD BIN FLOZT,
```

The variables are described below:

VARIABLE	DESCRIPTION	FIELD LENGTH IN # OF BYTES
TIME	Absolute time in seconds	4
ID	Aircraft ID.	7
FLG	(An empty field)	1
XAC	X-coordinate of aircraft in nmi.	4
YAC	Y-coordinate of aircraft in nmi.	4
ZAC	Altitude of aircraft in feet (MSL)	4
GSPD	Ground speed in nmi/sec.	4
XD	X-coordinate of ground speed in nmi/sec.	4
YD	Y-coordinte of ground speed in nmi/sec.	4
ZD	Vertical speed in feet/sec	4
TOTAL		40

The coordinate system used is shown in Figure D-1. RWY 34 is used as the Y-axis and as the reference direction for bearings. The origin is at the center of the runway.

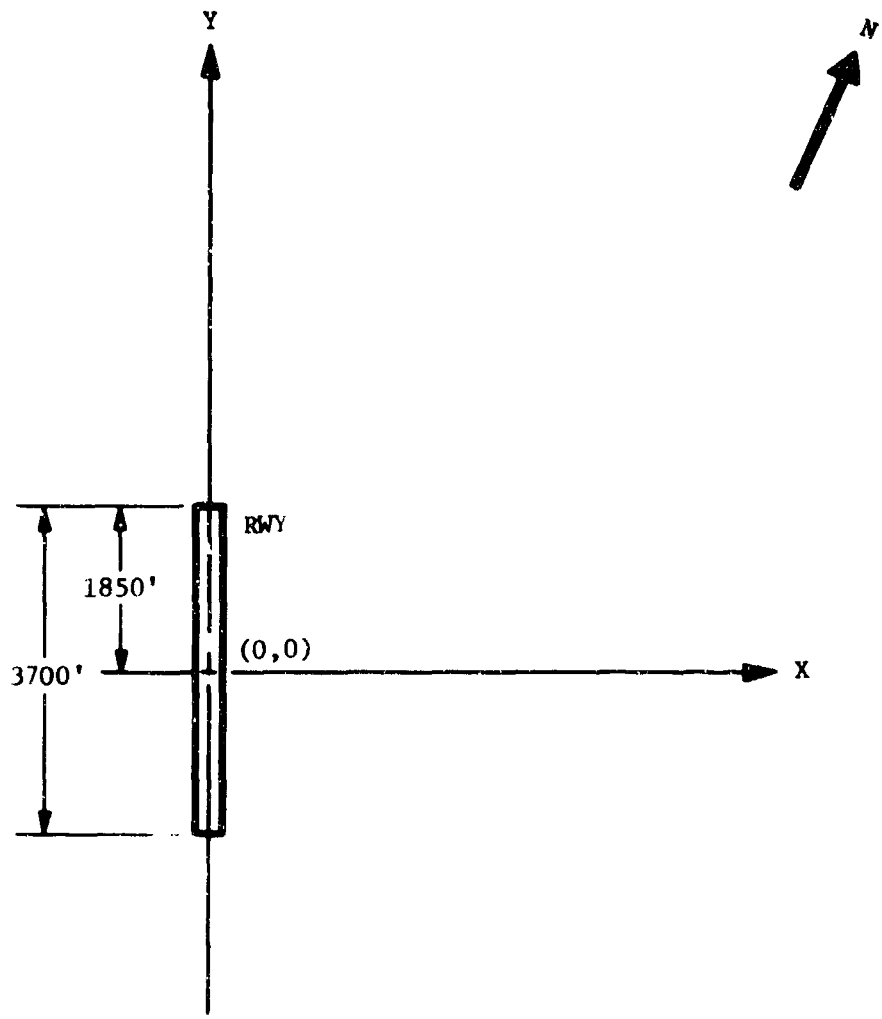


FIGURE D-1
THE COORDINATE SYSTEM

APPENDIX E

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